SUSTAINABLE CITIES: DETERMINING INDICATORS OF DOMESTIC ENERGY CONSUMPTION

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Abstract

The energy used by domestic dwellings currently accounts for 27.5% of total UK energy demand. Reducing domestic energy consumption and improving energy efficiency is a cornerstone of the UK's strategy to meet its commitments under the Kyoto Protocol. The impact of many factors influencing domestic energy consumption are well understood, however differences in consumption are the result of many complex direct and underlying relationships involving many factors that are not yet fully understood.

This thesis describes the development and implementation of a methodology for elucidating knowledge of factors influencing differences in domestic energy consumption using a postal questionnaire. This was based around the data requirements of the NHER Level 1 Site Surveyor form for houses and bungalows and extended to include questions on a wide range of other factors expected to influence consumption. Individual annual energy consumption data for these dwellings was obtained from the Department of Trade and Industry using a mandate form designed as part of this study, which represents the first time this data has been released to researchers in the UK.

The study identifies those variables found to be most significant determinants of differences in domestic gas and electricity consumption and reports the strength and statistical significances of the relationships found. Distinct clusters of energy consumers were discovered within the samples and their presence explained by differences in a small set of variables including floor area, occupancy, numbers of bedrooms and homeworking. Confirmatory analyses are performed to identify the most statistically significant variables for explaining differences in gas and electricity consumption. Clusters of technology users were also discovered within the samples and found to be related to electricity consumption and explained by differences in PC and digibox ownership and broadband access. An application

of the findings to the Building Research Establishment Domestic Energy Model sub-model for lights and appliances is demonstrated.

Author Declarations

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification.

The material included in this thesis has not been submitted wholly or in part for any award or qualification other than that for which it is now submitted.

Keith J. Baker
April 2007

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When I first started this thesis Google had just launched its invite-only e-mail service and in return for a mention here I was sent one by Min Jung Kim.

Finally, a huge thank you to my parents for helping me through another three and a half years in higher education. I promise that this is it - well for now anyway ☺

"Be reasonable, and demand the impossible now."
Robb Johnson

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Chapter 1. Introduction

1.1. Domestic Energy Consumption

Following the UK Government's 2006 Energy Review (DTI, 2006) much attention has been focused on changing the way we generate electricity and the potential use of a new generation of nuclear power plants to meet their Kyoto targets (DEFRA, 2005a) but this is only part of the solution. The role of reducing energy consumption, and in particular improving the energy efficiency of domestic households cannot be underestimated. In the UK 27.5% of energy consumption is attributable to domestic usage (DTI, 2006b). This figure alone indicates the potential for reducing energy consumption, and subsequent greenhouse gas emissions, by improving domestic energy efficiency.

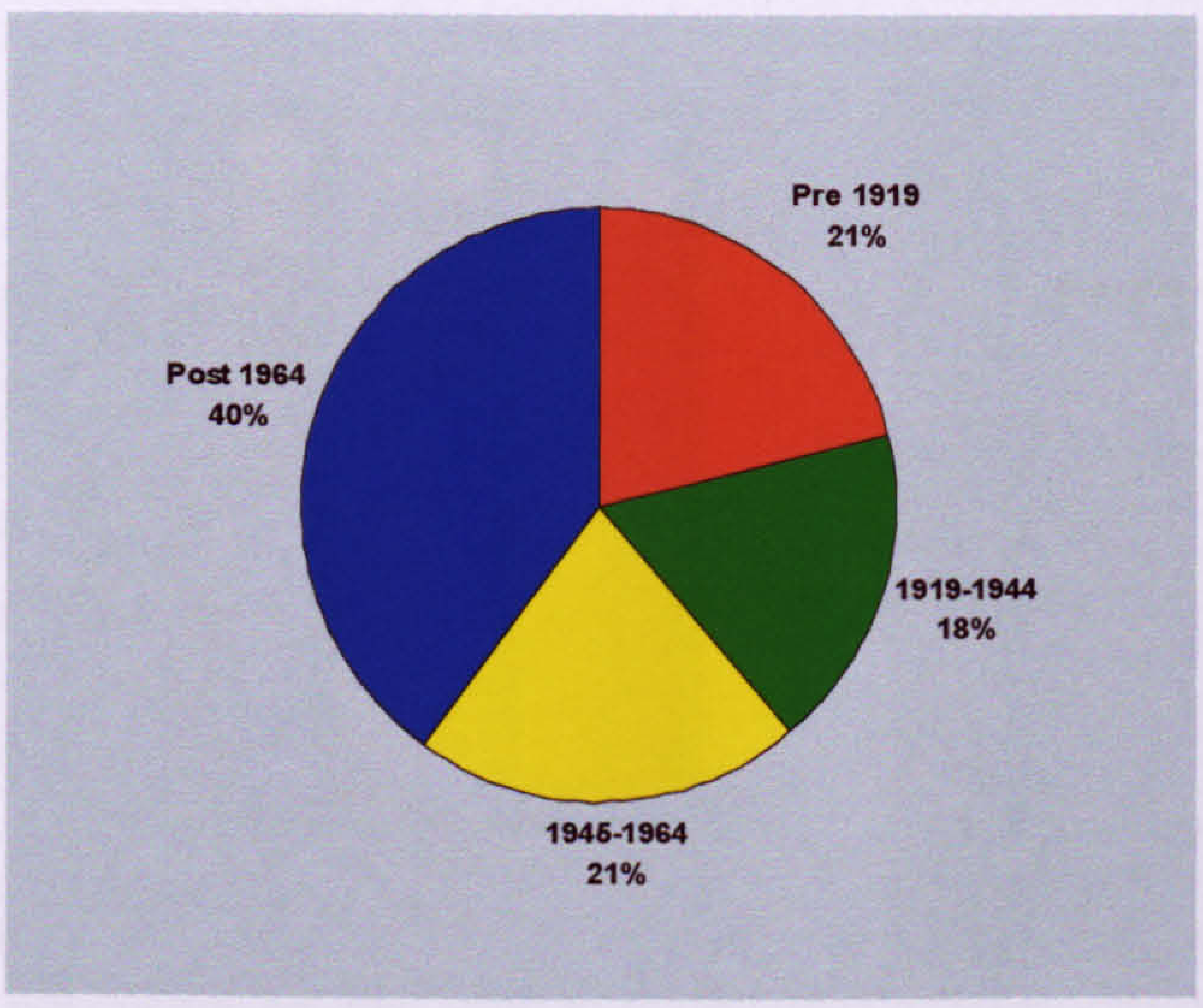


Figure 1.1. - UK Housing Stock by Age
(Reproduced from ODPM, 2001)

As shown in Figure 1.1, a significant proportion (39%) of the UK's housing stock was constructed before 1945. This is indicative of the high density developments built to house workers following the Industrial Revolution, and reflects a trend of re-use and renovation of existing dwellings in the post-war years. It also raises important questions as to how energy efficient this aging stock is, and how great an impact targeted energy efficiency schemes can have on reducing domestic energy consumption in order to help achieve the Kyoto targets.

A further indication of the density of UK housing stock is shown in Figure 1.2. Whilst semi-detached properties comprise the largest individual category, terraces and flats make up 47% of all UK dwellings. Lower density bungalows and detached properties combined account for a mere 24%. Whilst the trend for new build since 1970 has shown a gradual shift towards lower-density developments, with the proportion of detached dwellings increasing by 5.6% and the proportions of semis and terraces decreasing by 3.8% and 3.2% respectively, the proportion of flats has risen by 2.3%.

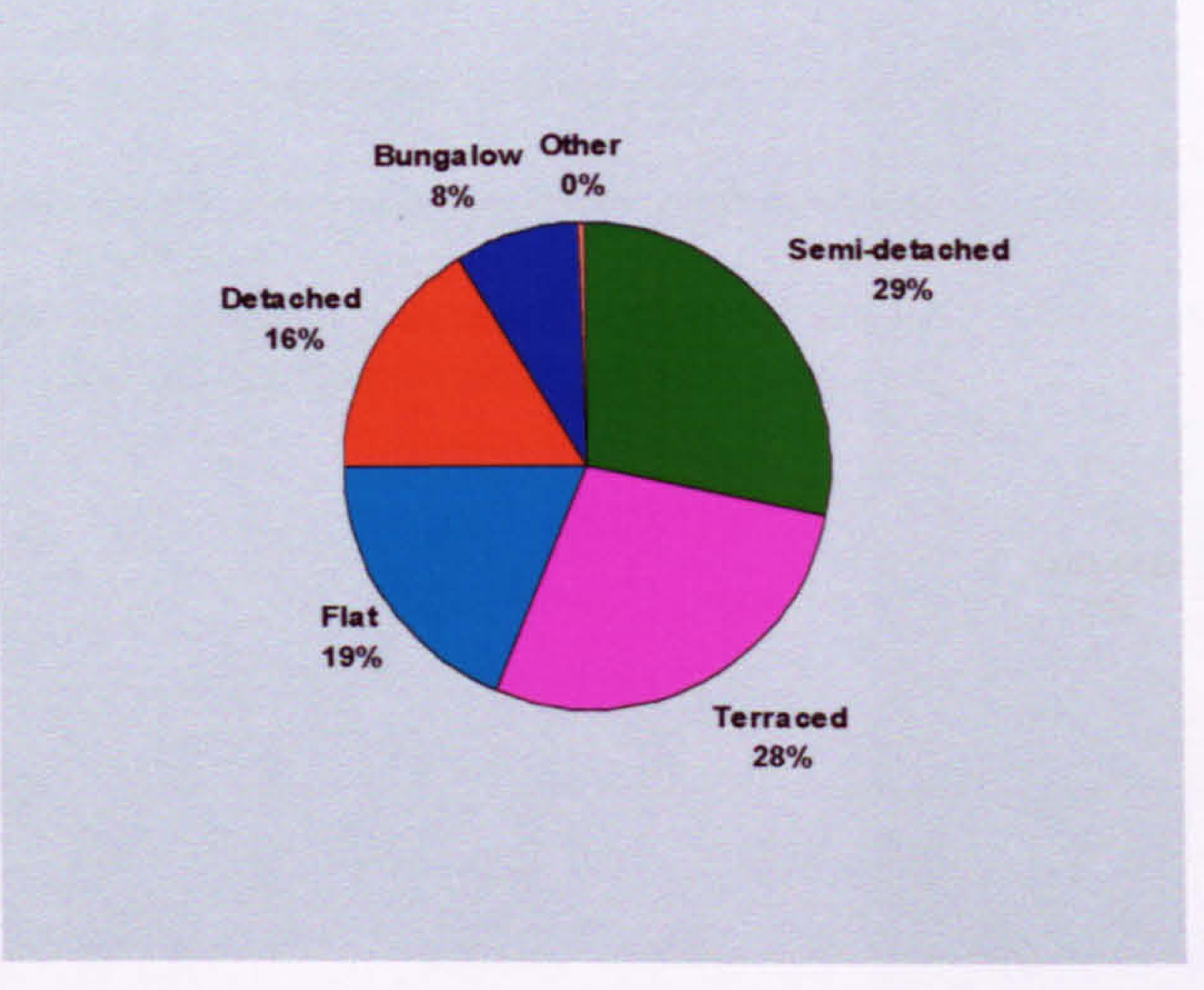
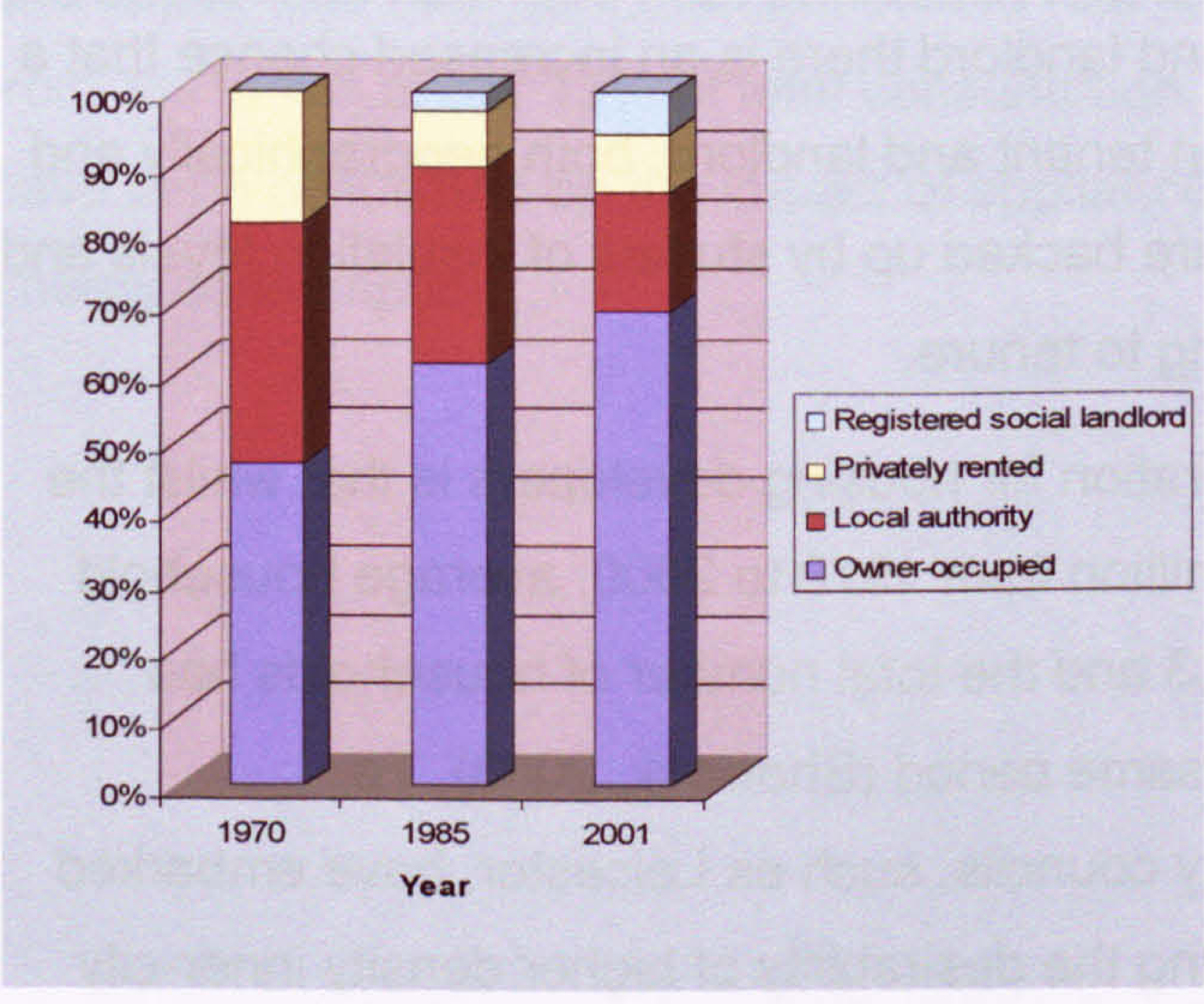


Figure 1.2. - UK Housing Stock by Built Form
(Source: Shorrock & Utley, 2003)

This changing proportion of stock raises important questions as to whether lower or higher density developments are preferable in terms of reducing energy consumption and the wider issues of urban sustainability. As discussed in Williams (2000) there is a strong argument that the 'compact city' represents a sustainable urban form suitable for densely populated nations such as the UK, but others have argued that variants of the compact city model, such as 'urban villages' have greater benefits in terms of improving sustainability and the quality of urban environments.

Changing patterns of ownership may also have implications for how best to target energy efficiency schemes. As illustrated by Figure 1.3, owner-occupancy has shown a steady increase since 1970, and although the number of dwellings rented from local authorities has declined some of this decrease is accounted for by ownership switching to registered social landlords and housing associations. The most interesting change is in the number of privately rented properties, which fell from 1970 to a low point in 1988, but has subsequently shown to be increasing again. This may well be a reflection of an increasingly mobile workforce and a greater number of households comprised of students and non-related young professionals.



Number of Dwellings by Tenure (1,000's)				
	Owner-occupied	Local authority	Privately rented	Registered social landlord
1970	8454	6206	3328	0
1985	12884	5903	1682	548
2001	16800	4103	2077	1442

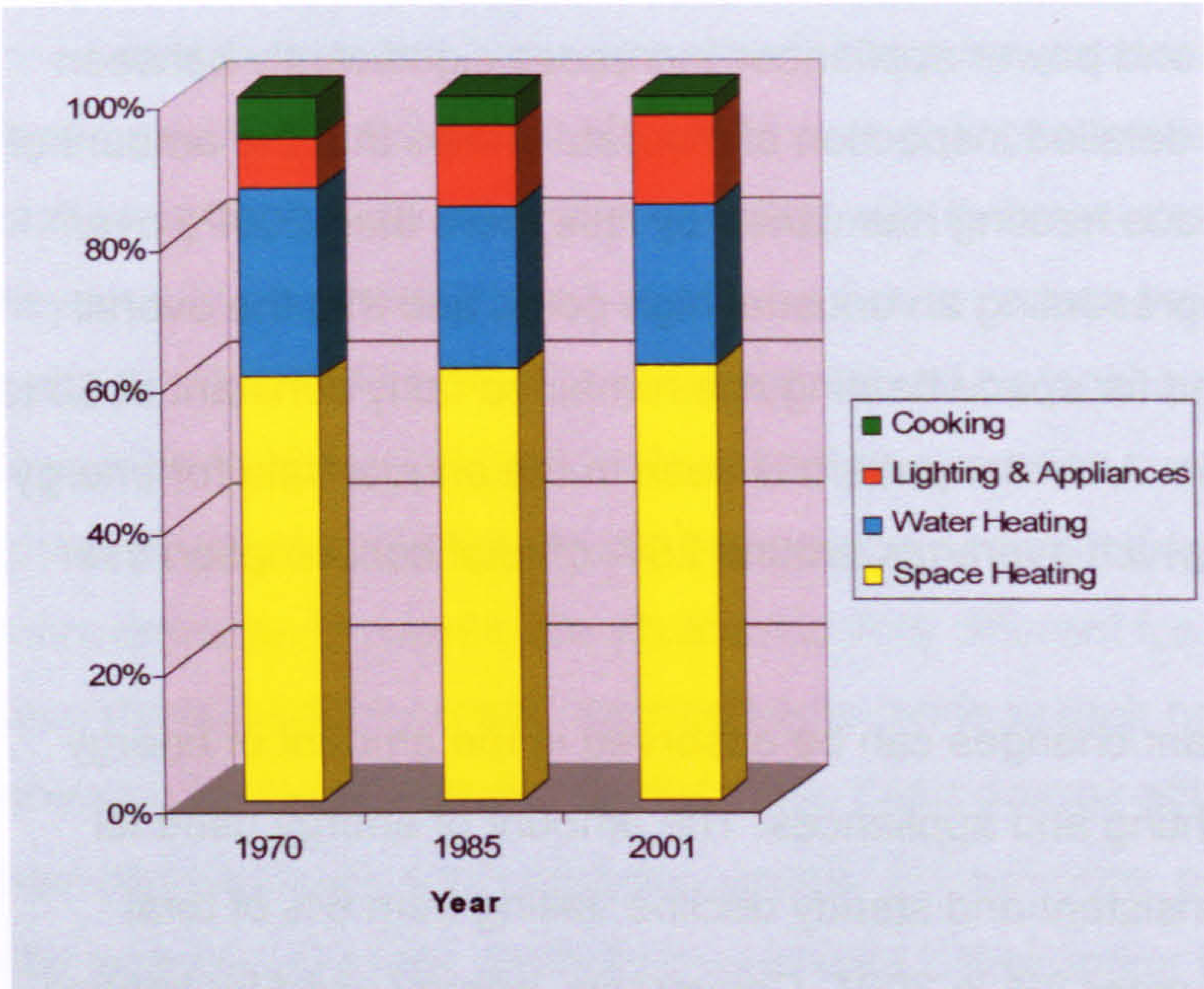
Figure 1.3. - UK Housing Stock by Tenure (selected years)
(Adapted from Shorrock & Utley, 2003)

In theory owner-occupiers should have the greatest knowledge of their dwellings, the greatest level of control over changes made to them, and being totally responsible for all bills associated with their maintenance and operation they should also have the greatest incentive to reduce their energy consumption. A similar argument applies to dwellings owned by local authorities and housing associations as benefit payments subsidise operation costs, and maintenance costs can be reduced by regular inspections and installing energy efficiency improvements. However, the situation is very different for private renters who have the least control over improvements made to their homes and very little incentive to invest in anything other than basic energy efficiency measures due to their comparatively short tenancy periods. Furthermore, private landlords have little incentive to make costly improvements if their major impact is to reduce the bills paid by their tenants. Where letting agencies form a link in the chain of communication between tenant and landlord there is an increased chance that a greater distance will exist between tenant and landlord, both geographically and figuratively. These assumptions are backed up by studies of insulation levels and uptake of double glazing according to tenure.

Another important consideration for housing developers is that whilst the UK population increased by 4.1 million from 1970 to 2000, average household size has decreased from 2.9 to 2.3 and the total number of households has increased by 6.4 million over the same period (Shorrock, 2003). To accommodate this trend many city councils, such as Leicester, have embarked on programmes aimed at promoting the desirability of higher density inner-city living. These schemes have apparent advantages in reducing energy consumption for transport, but their wider impact is questionable given that the fastest growing source of emissions from transport is air travel, and that whilst the proportion of UK energy consumption from this sector rose from 25% to 26% between 1990 and 2001 domestic energy consumption increased its share from 29% to 32% (DTI, 2002 and 2006).

Finally, and of key interest to this study, is the changing proportions of the end use of energy in our homes. As shown in Figure 1.4, the amount of energy used to light our homes and power appliances increases significantly between 1970 and 2001. A more detailed inspection of the data shows that the amount of energy consumed by space heating has varied by little more than 200PJ over this period, with 2001 representing an unusual high point, and that the overall proportion of energy used for space heating has remained fairly constant at 60 to 65% of total consumption. A similar pattern is seen in the annual data for energy used for water heating, which averages around 25% of total consumption over the period.

The most significant changes can be observed in the amount of energy used for cooking and lighting and appliances. The amount of energy used for cooking has shown a consistent and steady decline, falling from 6% of total consumption in 1970 to under 3% in 2001. Conversely, energy used for lighting and appliances has more than doubled in real terms and has risen proportionally from 7% to just under 13% of total consumption, yet to date relatively few studies have been conducted on the impact of appliance ownership and use on domestic energy consumption.



End Use of Energy (PJ)					
Year	Space Heating	Water Heating	Lighting & Appliances	Cooking	Total Energy
1970	901.4	402.2	108.4	89.5	1501.5
1985	1036.2	391.7	195.9	72.6	1696.3
2001	1222.1	448.8	249.6	53.7	1974.3

Figure 1.4. - UK Domestic Energy Consumption by End Use (selected years)
(Adapted from Shorrock & Utley, 2003)

This data has important implications for researchers conducting studies of domestic energy efficiency and those working to reduce emissions from domestic dwellings. Models that emphasise the role of differences in building envelope and services may be failing to account for changes in way householders use their homes and the appliances they equip them with. Tightening building regulations and improving legislation to increase the minimum energy efficiency requirements for space and water heating obviously have demonstrable impacts on reducing consumption, but this is only part of the challenge of reducing emissions from domestic dwellings as a contribution to achieving the UK's targets under the Kyoto Protocol. Proportionally, the most significant changes in domestic energy consumption are occurring in areas that reflect changes in our society and behaviour as consumers.

Despite a rapid rise in the use of energy efficient light bulbs for domestic lighting (section 2.2.5) and the introduction and expansion of energy efficiency labelling for major appliances (section 2.2.6) from 1995 onwards, consumption of energy by lighting and domestic appliances continues to rise. The data presented in this section suggests that a greater ratio of the number of households compared to occupancy levels has led to more light sources and appliances being shared by fewer individuals, but the true picture is unlikely to be this simple. Consumers are purchasing greater numbers of appliances, particularly high-tech goods, and whilst some, such as microwaves and LCD televisions, reduce the usage of other appliances or replace less efficient technologies, others will introduce additional energy demands. One example of the latter is the impact from digital, cable and satellite TV boxes being left on standby rather than being switched off because of poor design and/or unacceptable reboot times.

Behavioural studies may throw some light on this area of investigation but require intensive recording on behalf of participants, and in addition there is the distinct possibility that through involvement with such studies participants will be induced into changing their behaviour, perhaps even only for the duration, and reporting behaviour biased towards appearing more energy efficient than they really are (the well known Hawthorn effect, Van Wagner, 2007). However, there is still much scope for making contributions to knowledge of factors influencing differences in domestic energy efficiency in the UK using less invasive methods that focus on manifested behaviour with regard to ownership and use of types and numbers of lights and major domestic appliances.

1.2. The Urban Form Context

These studies are part of the City Form project, a multi-disciplinary consortium composed of five universities, each studying different aspects of urban sustainability (De Montfort – energy; Oxford Brookes – social; Sheffield – environmental; Heriot Watt – economic; and Strathclyde – transport) in relation to local and global aspects of urban form. Each university selected three study areas within their respective cities (Leicester, Oxford, Sheffield, Glasgow and Edinburgh) with the aim of representing contrasting elements of urban form found in the UK to enable comparisons to be drawn across and between each city. They represented three common city environments: the city centre, a city edge area and an 'in between' area. In each area 2,000 to 3,000 dwellings were selected by grouping together Output Areas (the smallest spatial unit used for grouping data from the Office of National Statistics 2001 Census). The use of these small output areas allows any data collected from the study areas to be compared at the same grain of analysis with census data without any of the bias that might be induced by using data aggregated over a much larger area, for example a Local Authority. A questionnaire was developed to provide data mainly for the socio-economic studies together with a methodology for the rapid site survey of the study areas and the description and measurement of urban form.

For the energy study it was initially envisioned that work would be carried out in all fifteen study areas, but as the methodology developed it became clear that this would not be feasible. The main reason for this was the lack of time and resources, but also that following the decision to aim to capture large groups of homogeneous dwellings within each area it was obvious that none of the city centre areas contained sufficient numbers of suitable dwellings and that some of the other areas met the criteria better than others. As such a sub-area of Birstall (Leicester) was selected for the more limited pilot study as it contained a small but very homogeneous group of semi-detached properties with a high level of owner-occupancy, and Clarendon Park (Leicester) Pollokshields (Glasgow) and Fulwood (Sheffield) were selected for the extended work.

1.3. Aims and Objectives

The aims of these studies were to establish the best general indicators of levels of domestic energy consumption that might be readily obtained from a survey of householders in the UK and to improve knowledge of the relationships between them, particularly those related to built form types and urban form measures. The main objectives were:

- To acquire insights through literature review into the scale and grain of domestic energy studies most relevant to the thesis aims.
- To design a survey instrument grounded in previous best practice and the requirements of simple domestic energy models that would best support the collection and capture of suitable data for the studies.
- To acquire energy consumption data from suppliers relevant to the proposed survey samples.
- To devise and apply a structured analytical approach – sensitive to the nature of the dataset – that would reveal groupings of relevance to energy studies and elucidate their relationships with energy demand.

1.4. Structure of the thesis

This thesis comprises ten chapters. After the introductory chapter the following chapters lead up to the final chapter containing the conclusions.

- **Chapter 2 – Literature Review** discusses the evidence for factors influencing domestic energy consumption and places this work in the context of previous studies.
- **Chapter 3 – Survey Methodology** describes the development of the questionnaire with reference to existing domestic energy surveys, in particular the National Home Energy Ratings Service (NHER) Level 1 Site Survey form for houses and bungalows, and home energy efficiency questionnaires used by local authorities. It covers the draft of the questionnaire used for the pilot project in Birstall and how the results of this project informed the revision of the questionnaire to produce the final version used for the full study. It also describes the various methods employed to gain access to energy consumption data for those respondents who gave their permission, which ultimately led to the release of this data from the Department of Trade and Industry (DTI). This study is

the first, and to date only, time that this individual consumption data has been released to researchers.

- **Chapter 4 – Descriptive Statistics and Secondary Data** discusses the composition of the full datasets (including those for which consumption and floor area data could not be obtained) and relates them to the statistics for the areas at the smallest scale that these were available free of charge.
- **Chapter 5 – Analytical Techniques** provides an overview of the statistical tools employed to analyse the data and definitions of the tests used to determine the strength and significance of the relationships found, and evidence of collinearity between the variables.
- **Chapter 6 – Determination of Groups of Energy Consumers** describes the use of two step cluster analysis on the records that could be matched with floor area and consumption data to determine if distinct groups of energy consumers were present within the combined dataset and individual study areas. The clusters are related to built form and used to inform the identification of a set of variables found to have the strongest influence on domestic energy consumption.
- **Chapter 7 – Further Exploratory Analysis using Simple Regression** details the use of simple linear regression to establish the strength of correlations between energy consumption and total floor area within groups within the study areas categorised by the variables from the questionnaire.
- **Chapter 8 – Confirmatory Analyses and Discussion of Key Findings** presents the results of the multiple regression analyses used to confirm the significance of the variables identified from the exploratory analyses. Where the results were suggestive of collinearity between these variables the statistical evidence is detailed and discussed. The most important findings are discussed with reference to previous studies. Further

variables are introduced into the multiple regressions and the chapter presents a series of tables produced from these analyses that give the strength and significance of those variables identified as having the greatest influences on electricity and gas consumption. The influence of these variables is discussed with reference to the tables and existing knowledge.

- **Chapter 9 – Further Analyses of Domestic Electricity Consumption and an Example Application** contains the results of a successful attempt to develop and indicator of electricity consumption based on a sub-set of the variables identified in the previous chapter. The approach uses two-step clustering to identify groups of technology consumers within the combined dataset, correlates these clusters with electricity consumption, and uses the socio-demographic data from the questionnaire to explain some differences in their composition. The chapter also describes the application of the BREDEM sub-model for lights and appliances (implemented in spreadsheet format using Excel) to the data from the three study areas, and several modifications of the model to account for differences in lighting and appliances.

Chapter 2. Literature Review

2. Introduction

This chapter has two main two sections. The first is an overview of previous studies of domestic energy usage and efficiency; it discusses their scale and granularity with particular emphasis on those most comparable to the present studies (as originally envisaged as part of the preparatory discussions for the wider City Form project). The second discusses previous investigations into specific factors relating to domestic energy consumption within built forms common to the UK.

2.1. Domestic energy usage and efficiency

Most studies carried out to date have either involved intensive measurements of small numbers of dwellings or studies of large numbers of dwellings at regional or national levels, both of which have inherent advantages and disadvantages. Small scale studies produce detailed results but are restricted in their treatment of different built forms, and may not be applicable to the wider urban environment. On the other hand large scale studies produce much broader pictures of energy use within different urban environments but risk overlooking smaller details which may have a significant cumulative impact.

At one extreme, the work of Adra et al. (2001) is an example of a small scale study on a single family house near Lyons in France. Approaches such as this require households to be fitted with meters to measure temperature, lighting, and appliance energy consumption, etc, as well as gaining access to make detailed measurements of dwelling construction and insulation. Larger studies have been conducted in the UK, for example Bell and Lowe's (1998) study of the energy efficient modernisation of a group of dwellings in York, however even this was still limited to only 30 cases. Although highly accurate they are necessarily resource-intensive methods involving considerable intrusion into the households being studied, and so are generally unsuitable for application beyond a small number of dwellings.

At the other extreme, investigations into domestic energy consumption over larger urban areas often combine a range of techniques that include archive searches, 'drive past' surveying, questionnaires, remote sensing, GIS applications, and in some cases modelling. An example of such research is the domestic energy use sub-model of the Energy and Environment Prediction (EEP) model developed by Jones et al. (2000 and 2001) which demonstrated an approach using GIS and information collected from drive-pass surveys to investigate the relationship between urban form and energy use, and its subsequent environmental impact. In this study each property was grouped according to location, building dimensions, age, and built form, and then given a Standard Assessment Procedure (SAP) rating using a computer program developed for use within the EEP model. Built form was categorised by surveying the number of storeys, number of chimney pots, window area, façade area, storey area, and the ratio of window to wall area. Location and dimensions were obtained from GIS coverages, and historical records were used to provide the dwelling age. Assumptions were made for remaining elements of the dwellings such as the U-value of walls, age of floor and roof, water heating system, water tank volume, and the space heated by a wall-mounted boiler. The assumptions were then validated using a questionnaire. An example of a study carried out at regional to national level is the methodology pioneered by Aydinalp et al. (2004) in Canada. This was based around a technique using neural networks for estimating energy consumption and the impact of socio-economic factors in the residential sector.

Most relevant to the work envisioned for the present studies were the investigations that focus on several hundred dwellings, and so most appropriate for comparison with the City Form study areas. The number of studies at this meso-level remains relatively few, especially in the UK. This is perhaps surprising as the urban form of many UK cities lends itself well to this scale of investigation, and Output Areas (the smallest regions used by the National Census for collating and analysing data) can be quite homogenous in terms of built form where they cover predominantly residential areas. These were the units used to construct the City Form case study areas, as described in Chapter 1.

The energy modelling of estates and neighbourhoods conducted by Alexander et al. (1997), and Perkins' (2002) work on groups of homogeneous dwellings in Australia, are two examples of such studies. Perkins' work is of particular interest in the context of this thesis as the study was able to investigate energy consumption amongst highly homogeneous groups of dwellings by selecting dwellings of a standardised construction and internal layout. Therefore it was possible to study correlations between energy consumption and factors such as appliance ownership within each built form type. A variation on this approach on a similar scale is that used by Newton et al. (2000) where measuring operational energy use was restricted to the main domestic energy demands of heating and cooling.

Alexander (1997) places a greater emphasis on the role of occupancy in determining differences in domestic energy consumption, at the scale of "housing estates" (the sample size is not stated). In terms of covering manifested behaviour (i.e. physical measures taken to reduce consumption such as improving dwelling insulation, rather than reported behaviour such as switching off lights and appliances when not in use) this is useful as occupants are not treated as automatons in a system. However, by including attitudes and behaviour it risks inducing propagational errors through inaccurate reporting and contextual bias on behalf of respondents.

One of the few investigations to focus specifically on the operational energy consumption of domestic dwellings is the development of the Canadian End-use Energy Model by Fung et al. (2000), which combines data from the Canadian Survey of Household Energy Use (SHEU, a survey of 8767 dwellings), the Modified STAR-Housing Database and the 200-House Audit Project Database to assess the potential for emissions reductions of various energy efficiency improvements. Like Perkins' study this used energy consumption data, but in this case it was obtained from utility companies (for a sub-set of 2524 of the dwellings surveyed for SHEU) and used to validate the output from the HOT2000 Building Energy Simulation program. .

Within any set resource limit the level of granularity achievable as part of investigating domestic energy consumption is invariably the result of trade-offs between scope and scale. An exception to this rule is the on-going Household Energy End-use Project (HEEP) being conducted by the BRANZ Ltd of New Zealand (BRANZ 2002, 2003 & 2004) which has developed a database of over 300 randomly selected and deliberately targeted dwellings from around the country and which have been subject to in-depth on-site monitoring and assessments. However such studies are rare and HEEP has required substantial public and private funding of a level that is unavailable to most energy researchers that has enabled the work to be carried out over a period of over 8 years (based on the latest freely available executive summary).

The next section compares approaches with different emphases on measuring and modelling energy consumption.

2.1.1. Measuring and modelling energy consumption

The most widely used approaches to assess or model domestic energy efficiency, such as EEP and SAP have proved highly effective in nations such as the UK which have inventories of built form that are predominantly older, and therefore have been measured extensively. These have produced accurate predictions of the impact of major energy efficiency improvements such as improved insulation and glazing. However, these studies have difficulties when attempting to account for variations that are more rapid but constitute smaller proportions of total energy consumption; this applies to lighting but particularly to appliance ownership and use. Conversely small-scale intensive studies such as Adra et al. (2001) can only capture a limited picture of the range and impact of the variety of lighting options and appliances now in use in our households. Sections 3.5 to 3.8 give a detailed discussion of these issues and why they need to be accounted for in order to improve the accuracy of models of domestic energy consumption. Existing models such as BREDEM (NEF, 2004) already account for heating, cooling, lighting and hot water yet they leave many other areas unexplored. Developing a more detailed knowledge of aspects of occupant behaviour, for example greater numbers of people choosing to work from home, and of the purchase and use of greater numbers of domestic appliances, particularly information and entertainment products, should be invaluable in informing future energy studies.

2.1.2. Statistical analysis of factors relating to domestic energy consumption

Regression analysis, in its various forms, remains the most common option for assessing the strength of the relationships between physical factors or manifested behaviour and energy consumption. Perkins (2002) makes extensive use of regression analysis however, as should be expected, observed correlations in such studies are very rarely at the levels of significance required in the pure sciences. The range of variables that need to be considered is simply too great and the underlying relationships between them are complex.

Modelling using existing methods such as BREDEM, where measured consumption can be used to validate the output (or otherwise) is also common. However, without the level of resources available to groups such as BRANZ it is extremely difficult to devise a study that could conclusively cover all the different energy sinks in an average household. Yet, given the lack of studies that have attempted to elucidate relationships between factors involved in energy consumption using less resource intensive methodologies, the potential value of such studies is correspondingly high.

The next section covers the numerous factors that influence domestic energy consumption.

2.2. Influences on the Operational Energy of Domestic Dwellings

As discussed in the introduction the UK's dwelling stock can be characterised as predominantly older and less efficient that that of most other countries in the developed world, reflecting the need to house the influx of people to cities and industrial centres around the time of the Industrial Revolution, and later to house the 'baby boomers' of the post-war period. Land and construction costs and high dwelling densities, in particular the terraced houses that are the characteristic built form of most cities, act as strong physical and economic deterrents to major structural renovations and new build in cities, and despite being a nation of owner-occupiers there are relatively few incentives for householders to improve the efficiency of their dwellings. Demolition rates are low and new build invariably adds to, rather than replaces, dwelling stock at a current net gain of just under 200,000 dwellings per year, equivalent to ~1% of the total stock (DETR, 1998).

Figure 2.1 shows how domestic energy consumption by use changed between 1990 and 2002.

This section gives an overview of factors influencing energy consumption and efficiency in UK dwellings, the potential for improvements to reduce energy consumption and emissions, and draws some comparisons with the situations in other countries.

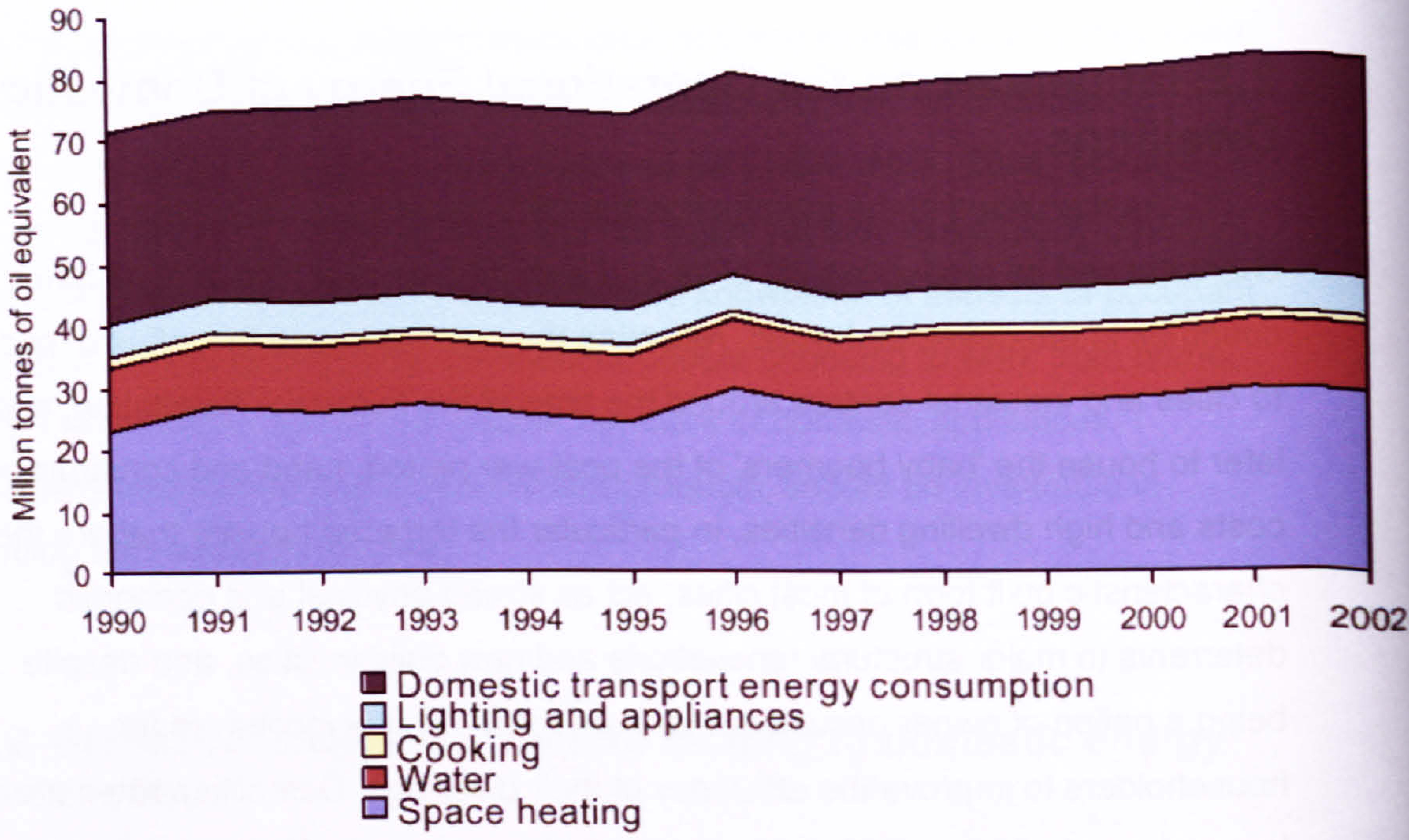


Figure 2.1. Domestic energy consumption by use for 1990 to 2002
Source: DTI (2003)

2.2.1. Dwelling Construction

Given the longevity of UK dwellings the time and standard of construction should be key indicators of overall energy performance. UK building regulations have been updated with increasing frequency over the last 50 years, with the minimal standards for insulation improving each time, and forthcoming government legislation will see all new dwellings given an energy efficiency rating similar to those used on domestic appliances. An example of this progress is that 2006 efficiency standards are 40% higher than those from 2002, and 70% higher than for 1990. The rate and impact of this progression is shown in Figure 2.2.

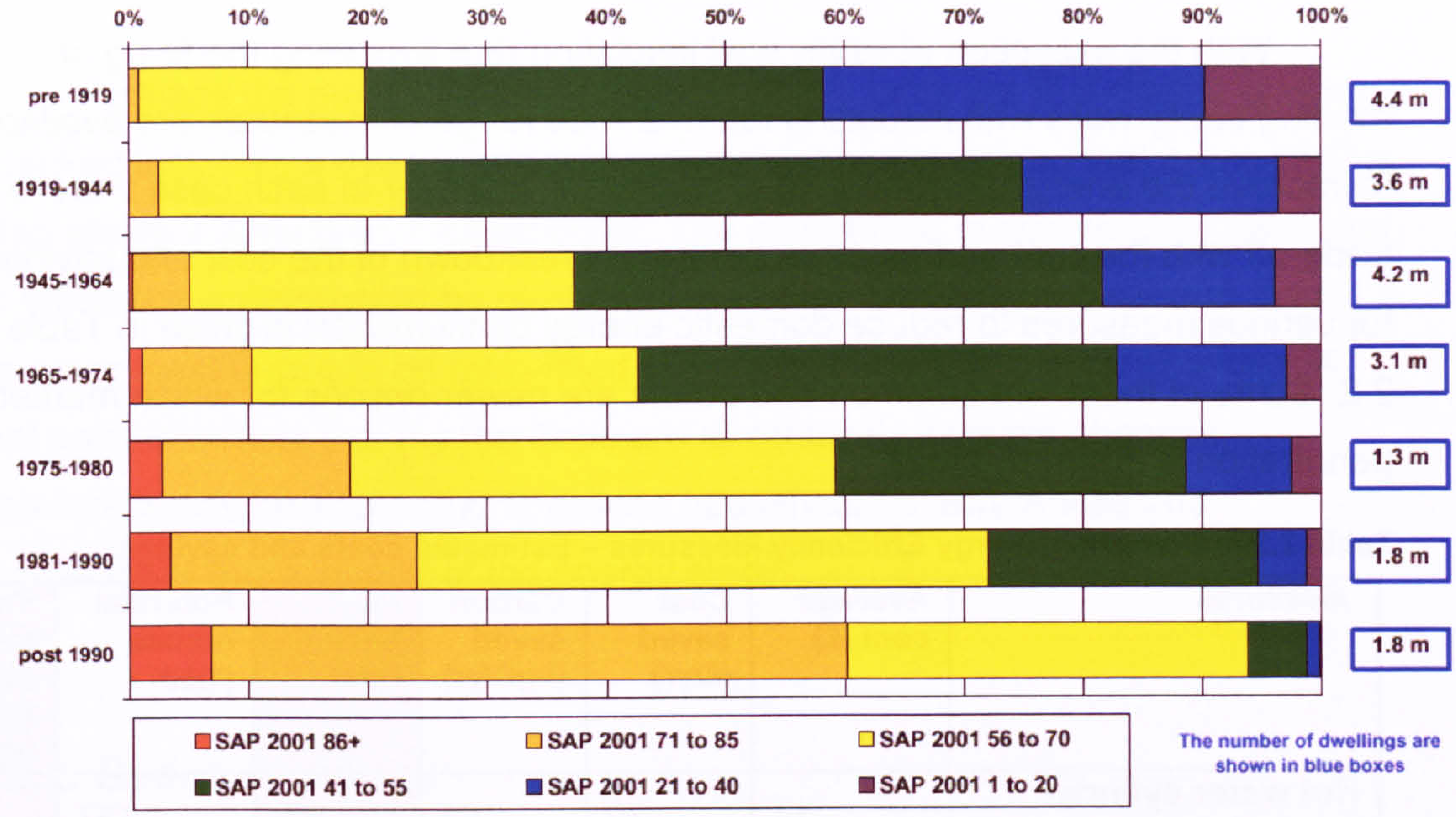


Figure 2.2. – Profile of Energy Performance in Existing Dwelling Stock, 2004
Source: DCLG, (2006)

Another factor that will need attention is that the practice of fitting out new homes with major appliances is now commonplace, but if the same standards are applied to fittings as to construction the overall efficiency of UK dwellings can be expected to improve relative to construction rates. However, this of course only applies to new build and therefore the greatest potential to reduce emissions from homes lies in the older existing stock. This is highlighted by Table 2.1, which shows the emissions savings that could be made by improving the efficiencies of existing properties by 10 SAP points.

Table 2.1. – Illustration of the effect of improving all existing dwellings by 10 SAP 2001 points
Source: DCLG, (2006)

SAP 2001 rating	Count ('000s)	*Current 2004* Emissions (MtC)	*Increase by 10 points* Emissions (MtC)	Average saving per dwelling (tC)	Total saving (MtC)
86+	283	0.2	0.1	0.1	0.0
71 to 85	2,268	1.8	1.5	0.1	0.3
56 to 70	6,082	6.5	5.4	0.2	1.0
41 to 55	7,593	10.6	9.0	0.2	1.7
21 to 40	3,438	6.9	5.8	0.3	1.2
1 to 20	873	2.6	2.1	0.6	0.5
Total	**20,536**	**28.6**	**24.1**	**0.2**	**4.5**

With the exception of cavity wall insulation (but excluding the filling of existing cavity walls with insulating foam) a wide range of measures are available to improve the energy performance of dwellings, however in each case there is a trade-off with the cost and payback period. A breakdown of the cost and savings for various measures to reduce domestic energy consumption is given in Table 2.2. Some of these are common and others are newer options for which market penetration is currently small.

Table 2.2. – Domestic Energy Efficiency Measures – Estimated costs and savings.

Measures	Average cost (£)	Cost saved (£/yr)	Carbon saved (kgC/yr)	Pay-back (yrs)	Potential homes ('000) †	Potential total carbon saving (MtC/yr)
Hot water cylinder insulation	14	29	53	**0.5**	1,137	**0.1**
Cavity wall insulation	342	133	242	**2.6**	8,500	**2.1**
Loft insulation (full and top-up)	284	104	190	**2.7**	6,186	**1.2**
Improved heating controls	147	43	77	**3.4**	2,102	**0.2**
Draught proofing	100	23	43	**4.3**	9,793	**0.4**
Micro CHP	1,571	230	508	**6.8**	12,000[4]	**6.1**
Solid wall insulation	3150	380	694	**7.5**	7,479	**5.2**
A-rated boiler	1,500[1]	168	177	**8.9**	17,128	**3.0**
Micro wind	2,363	224	263	**10.5**	-[2]	**-**
Ground source heat pump[3]	4,725	368	990	**12.8**	17,000	**16.8**
Photovoltaic (PV) electricity	9,844	212	249	**46.4**	9,892	**2.5**
Solar water heating	2,625	48	88	**54.7**	19,330	**1.7**
Windows (Single to Double Glazing)	4,000[1]	41	26	**97.6**	10,746	**1.7**

Notes (from DCLG):
1. Estimate based on currently available price comparisons.
2. Planning permission is currently required for this technology.
3. This is an emerging technology and is not yet widely commercially available to households. In addition, the estimated potential total carbon savings from installing ground source heat pumps is based purely on the number of houses with gardens (EHCS), but it is unclear for how many properties this technology may be feasible and is likely to be an overestimate. There are likely to be massive variations in installation cost as it is strongly affected by the geological and environmental conditions of the site.
4. J Harrison, EA Technology. This estimate is based on an emerging technology, which has not yet been fully explored for feasibility and potential in the UK.
Source: DCLG, (2006)

Perhaps the most interesting aspects of this table are that double glazing is ranked last, below even renewable energy technologies, and that micro-CHP is rated above installing an A-rated boiler. The importance of constructing dwellings for efficiency is highlighted by cavity wall insulation being ranked second, as all the other measures can be retro-fitted without significant structural changes. A final point of note is that the top three are all relatively invisible changes, therefore it may be interesting to assess householders' awareness and knowledge of them as part of the energy study.

2.2.2. Space Heating

Space heating constitutes the single largest use of energy in domestic dwellings and increased by 26% from 1990 to 2002. A study conducted by the utility company Powergen and quoted by the DTI showed that householders' first response to feeling too cold is to turn up the thermostat, closely followed by turning on additional heating (DTI, 2003). After dwelling construction space heating constitutes the second major factor in dwelling energy consumption that remains fixed over many years and requires significant financial outlay to replace. However, this slow rate of change means that energy consumption by space heating is well understood and documented, and energy models such as BREDEM and assessment methods such as SAP can take advantage of the detailed information available on most existing systems to accurately predict their impact on total household energy consumption.

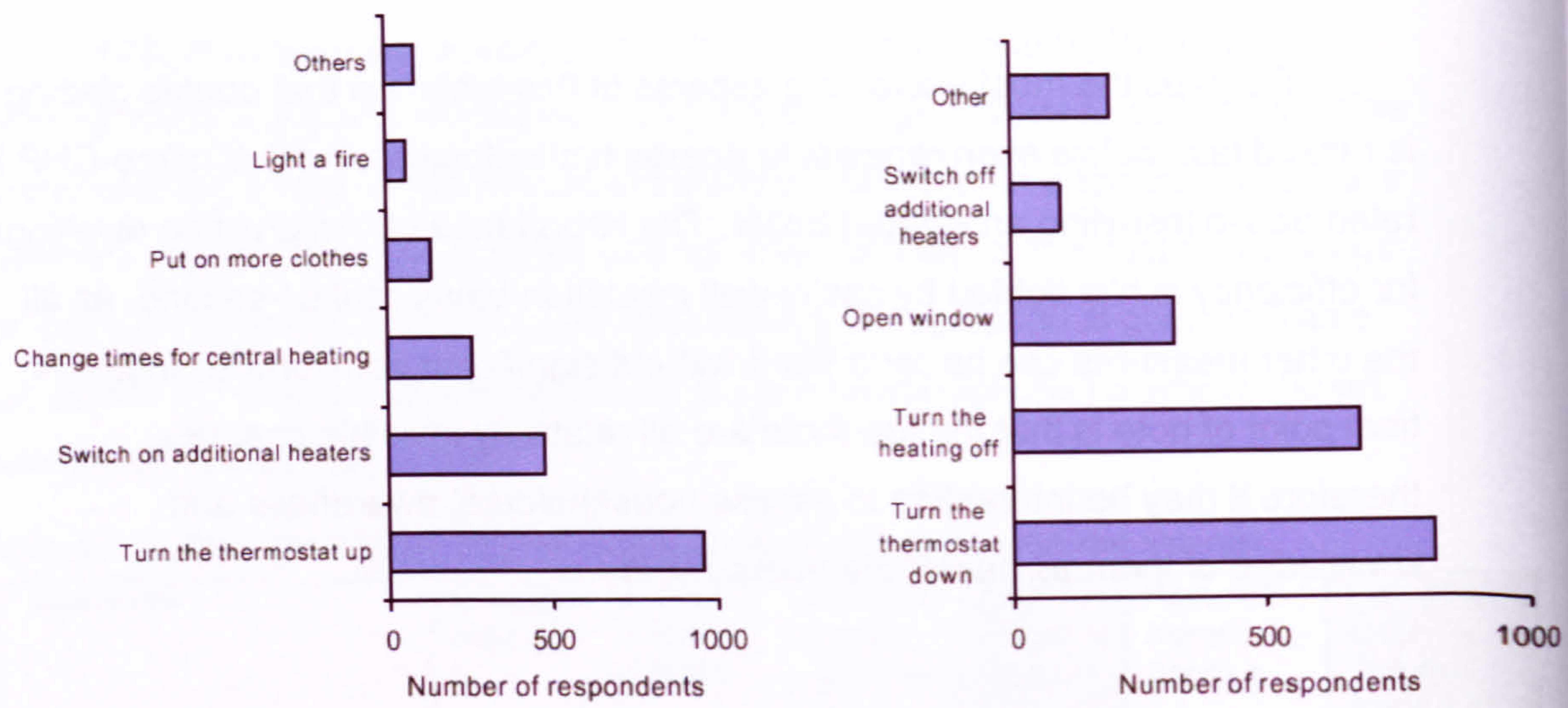


Figure 2.3. Behaviour in response to feeling too warm or cold
Source: DTI (2003)

The most effective means of reducing energy consumption by space heating is through behavioural changes that do not increase energy use when occupants feel too cold and reduce energy use when occupants feel too warm. These have been shown to reduce consumption by 10% for centrally heated dwelling and 17% for non-centrally heated dwellings, yet as shown in Figure 2.3 increasing heating levels or switching on additional heaters are still by far the most common responses to feeling cold. Furthermore, despite a modelled reduction of 43% in energy use, fitting dwellings with energy efficient gas fuelled central heating systems has been shown to produce no real reduction in consumption, even after adjusting for occupants using it to improve their levels of thermal comfort (Hong et al., 2006).

Overall, whilst the energy consumption of domestic space heating is well understood, reducing consumption is more dependent on improving dwelling insulation and encouraging behavioural changes, the latter being especially problematic as many UK dwellings do not provide the levels of thermal comfort desired by their occupants. What is less understood is the role of secondary heating, and how changing household compositions may change the common assumptions around domestic heating regimes.

In addition, as summer temperatures rise the UK is now facing the impact of householders beginning to purchase domestic cooling systems and future studies will need to account for this once the devices become present in significant numbers in UK homes.

2.2.3. Water Heating

With most UK dwellings being equipped with gas fuelled radiator systems for space heating, energy consumption by water heating is intrinsically linked to space heating. The UK is undergoing a shift in the most common forms of boilers found in dwellings, away from conventional boilers and towards combi and condensing models. According to government statistics condensing gas-fired boilers will account for 80% of all gas boilers in 2006, 86% in 2007, 87% in 2008, and 88% from 2009. Condensing oil-fired boilers will account for 5% of all oil boilers in 2006, rising to 40% (44% of non-cooker boilers, i.e. excluding Agas) in 2007, 66% (71% of non cooker boilers) in 2008, 66% (73% of non cooker boilers) in 2009 and 67.5% (75% of non cooker boilers) from 2010 (MTP, 2006).

However, hot water provision is not restricted to coming from a boiler. Almost all homes are equipped with at least one other device that heats water separately, for example showers, washing machines, dishwashers, and electric or gas single or multi-point water heaters. Some of these should serve to reduce energy consumption by reducing the daily period over which the main boiler is heating water, for example dishwashers reduce the need for hot water to be available for washing dishes and may make more efficient use of it. In addition, domestic water heating often uses both gas and electricity, therefore attributing consumption requires developing knowledge of the combinations of systems and appliances in use as well as household behaviour.

2.2.4. Cookers

Energy consumption for cooking represents a relatively small proportion of total domestic energy demand. As for water heating attributing consumption requires knowledge of the type of cooker and some assessment of household behaviour as many households use both gas and electricity to cook meals. The most common forms of cooker found in UK dwellings are gas or electric-only models and those with gas hobs and electric ovens, with kitchen ranges making up much of the remainder.

Figure 2.3 shows how electricity use by cooking appliances has changed since 1970, however the full picture is not well understood and there is comparatively little information available on energy consumption by cookers and household behaviour regarding their use. An exception is the DECADE study (Boardman, 1996) conducted by the Environmental Change Institute at Oxford University which highlighted several key trends. Ownership of gas hob and electric oven combinations increased from 1% to 9% over the period 1979 to 1993 is still increasing. The demographic shift towards increasing numbers of households is leading to a greater demand for energy for cooking, although to a certain extent this is being offset by the growth in single person households. The number of meals being eaten at home has fallen as increasing numbers of people eat at work, and whilst there has been a growth in the consumption of convenience food the energy saved is being offset by a growth in the ownership of labour-saving devices such as food processors.

A final impact on domestic energy consumption that is attributable to changes in cooking behaviour is the rapid growth in the purchasing of microwaves. Although relatively efficient for cooking meals many microwaves have a clock display and therefore fall into the category of 'always on' appliances. It has been estimated that as much as half of the annual energy use by microwaves is attributable to standby consumption, and this could be as much as 61 kWh per year based on 1995 figures (Boardman et al., 1996).

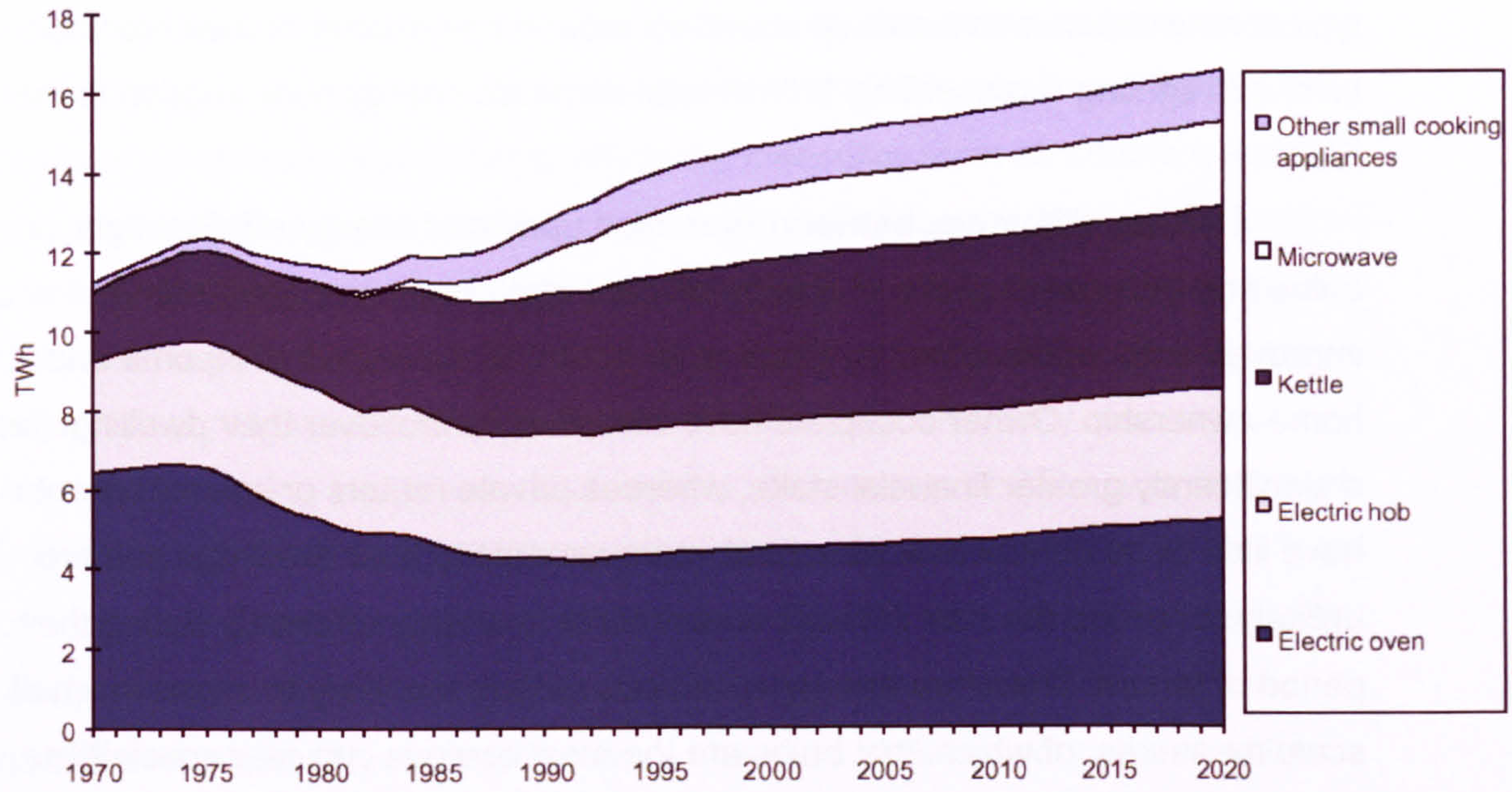


Figure 2.3. - UK electricity consumption by cooking appliances.
Source: Boardman et al. (1996)

2.2.5. Lighting

Lighting has traditionally been grouped with appliances when categorising factors determining dwelling energy consumption. This is understandable as calculating the electricity consumption directly attributable to lighting is not straightforward. Doing so entails breaking into lighting circuits in order to meter them and measuring the consumption of lights that are plugged into wall sockets. Where the consumption of each individual light is known alternative options are using sensors to monitor use or requiring participants to record their use. Clearly this is not possible at the scale of this study.

Oxford University's DELight report (Palmer & Boardman, 1998) simplified the problem of accounting for different energy regimes by focusing on one element of improving operational energy efficiency, that of replacing standard light bulbs with energy efficient equivalents. This EU study, focusing on results from the UK, Sweden and Germany, concludes that, under present conditions, a widespread switch to using energy efficient light bulbs has the potential to save typical householders in the three countries around one quarter of their electricity bills, with lighting representing 17% of total domestic energy consumption in the EU.

One key difference between increased uptake of energy efficient light bulbs and increased uptake of energy efficient appliances and other home improvements, as observed by Black et al. (1985) is the impact of income and home ownership. Owner occupiers have complete control over their dwellings, at a significantly greater financial stake, whereas private renters or council tenants have little or no control over structural improvements to their dwellings and are unlikely to recoup the cost of major investments in energy efficiency during their period of tenure. Therefore energy-conscious renters are likely to invest in small scale measures, of which light bulbs are the most obvious choice, especially as they can be easily removed when a tenant moves house. The exception here is renters of unfurnished properties whose main appliances (with the exception of built-in appliances such as the cooker) move with them. Such persons are in a position to see a financial return on the purchase of energy efficient appliances, however, as what constitutes a part or unfurnished dwelling is often somewhat unclear it is difficult to differentiate private renters according to appliance ownership.

Of all the schemes developed to improve domestic energy efficiency in the UK perhaps the most prominent has been the drive to encourage householders to install compact fluorescent lamps (CFLs). A widespread shift towards replacing conventional tungsten bulbs with CFLs has a significant potential to reduce domestic energy consumption, and compared to factors such as appliance ownership and use the savings attributable to CFLs should be easier to quantify. However in order to do so, and to predict the future impact of greater uptake of CFLs, information is needed on the current usage situation and the likely future rate of adoption.

Therefore another use for data on the number of CFLs in use in UK dwellings may be as an indicator of household energy awareness that can be used to infer a measure of overall energy efficiency practices and use this as a weighting factor in subsequent analyses. However, this assertion is partially contradicted by the earlier work of Mansouri et al. (1996) who found that unlike the take up of more costly energy efficiency measures such as double glazing and more efficient heating systems, where the main reason given was to improve comfort, 66% of respondents reported installing CFLs for economic reasons. Only 16% reported concern for the environment as a factor, although this was still a notably higher percentage than for other energy efficiency measures. Another interesting underlying relationship in the take up of CFLs was observed from this study of 110 individuals was the relationship between take up and level of education. The largest group of CFL users (22.1%) were educated to degree level, whereas the smallest (8.5%) was the group without any formal qualifications. Similar relationships were observed between education and the purchase of more energy efficient appliances and between socio-economic grouping and the installation of more efficient space heating systems.

These results are now ten years old but the paper remains one of the few to have investigated these relationships in any depth. As is discussed in section 2.3.7, in the time elapsed since the completion of the work the effects of the EU's mandatory appliance efficiency labelling scheme should have filtered through to the entire UK population so one interesting outcome of the energy study will be to test if these relationships still exist.

The following three sections look at the impact of appliance ownership and use on domestic energy demand, the implications of energy labelling and technology substitution, and how the next big technological shift, the digital switchover, may affect domestic energy consumption.

2.2.6. Impact of Appliance Ownership and Use on Domestic Energy Demand

The total amount of energy used to power lighting and domestic appliances has more than doubled in the last 35 years (DTI, 2003). What is perhaps surprising is that consumption has continued to rise despite the EU's introduction of energy labelling for major appliances and legislation to mandate minimum efficiency levels post 1995, and the increasing number of households using greater numbers of energy efficient light bulbs.

Some of this trend can no doubt be explained by the socio-demographic shift towards more households with fewer occupants and consumers purchasing more appliances, but this is highly unlikely to be the full story. Therefore a more quantitative approach that takes into account both technological and social change is needed to fully account for the impact of appliance consumption on total domestic energy demand.

The most important work on the impact of energy labelling is the DECADE project conducted by the Environmental Change Institute at Oxford University (Boardman et al. 1996). However, the labelling scheme is the subject of on-going revision, and a combination of technological change and new legislation makes it difficult to compare any two quantitative evaluations of its impact. In addition such studies require a high level of granularity to extract the portion of domestic energy consumption attributable to appliances, and predict its impact in order to produce accurate models. Given the necessary resources intensive on-site surveying and monitoring would provide invaluable data to inform the debate, but as well as being infeasible over large numbers of dwellings this risks introducing an element of participant bias.

The EU began implementing mandatory energy labelling and introduced the European Ecolabel for appliances as far back as 1995 (European Commission Directives 92/75/EEC, 94/2/EC, 95/12/EC, 95/13/EC, 96/60/EC, 97/17/EC, 98/11/EC, 2002/31/EC and 2002/40/EC) however, as discussed previously, given the assumption that most householders will have replaced many or all of their higher energy consuming appliances over the last ten years this has not led to a reduction in the amount of energy consumed by the UK's inventory of domestic appliances.

The labelling legislation currently covers fridges, freezers (and their combinations) washing machines, tumble dryers, washer-dryers, dishwashers, electric ovens, air conditioners and lamps, and the forthcoming Energy Using Products Directive (EuP, Directive 2005/32/EC) will extend mandatory efficiency standards to virtually every household appliance.

The DECADE project addressed the question of just how effective energy efficiency labelling is on influencing consumer choice. The study looked at recent purchasers of fridges and found that only 37% of interviewees noticed the label, and of these two thirds would have liked more information on the label, from sales staff or from in-store posters. Interviewees from professional and educational scientific or technical backgrounds proved most receptive to the labels. However, the report also found that when consumers noticed the label one third said their choice was influenced 'a great deal' or 'quite a lot', thus the researchers were able to conclude that, given enough appropriate information, consumers do tend to opt for more efficient appliances, and a distinct correlation was observed between the influence they reported and the efficiency of the appliance they bought (Boardman et al., 1996). Admittedly there were some caveats associated with these conclusions, for example at the time of the study there was a greater price differential between high and low efficiency appliances and a greater number of lower efficiency models on the market than exists now, however the report provides an invaluable insight into how consumers reacted to the labels immediately after their introduction.

In the time elapsed since the study it can be expected that most households will have replaced most of their major appliances (cold appliances having a turnover rate of around 15 years, with wet appliances being replaced more frequently) therefore there is now a timely opportunity to assess the impact of the labelling scheme on reducing the contribution of appliances to overall domestic energy consumption. As is shown in Figure 2.5 energy consumption by cold appliances exhibited a decline on 1990 levels within five years of energy labelling coming into force, however this is vastly offset by the increase in ownership.

Further questions relating to the effectiveness of energy labelling and the accuracy of studies investigating its impact are raised by Meier's (1997) study of a US initiative to improve the efficiency of electric showers. The study addressed three main pitfalls associated with a reliance on labelling to reduce consumption as follows: failure on the part of the body administering the scheme to develop accurate standards and enforce them, leading to non-compliance from manufacturers; incorrect estimations of the energy use of existing appliances, leading to errors in predictions of energy savings; and changes in the way consumers use appliances. The study provided evidence that these three factors have led to a significant divergence in predicted and actual savings from energy efficiency legislation. It identified failures such as the use of professional judgement and anecdotal evidence to provide a baseline for consumption; the lack of accounting for the savings from low-flow showerheads by relying on manufacturers' specifications; the failure to account for the results of research that showed that households with more efficient showerheads shower for longer; and the use of the assumption that each US household heats 240l of water per day, a figure which was 20 years old at the time of the study. Field tests would have shown up these errors, but their absence led to an unrepresentative estimate of baseline demand and an inaccurate estimate of operational demand, both of which left manufacturers with little incentive to improve their products.

The most important lesson here is the necessity for field testing to gain accurate data on which to base estimates of baseline demand, and therefore to calculate accurate estimates of the real savings from efficiency improvements. However, it also highlights how subtle changes in the way householders use appliances can have noticeable cumulative impacts on energy consumption.

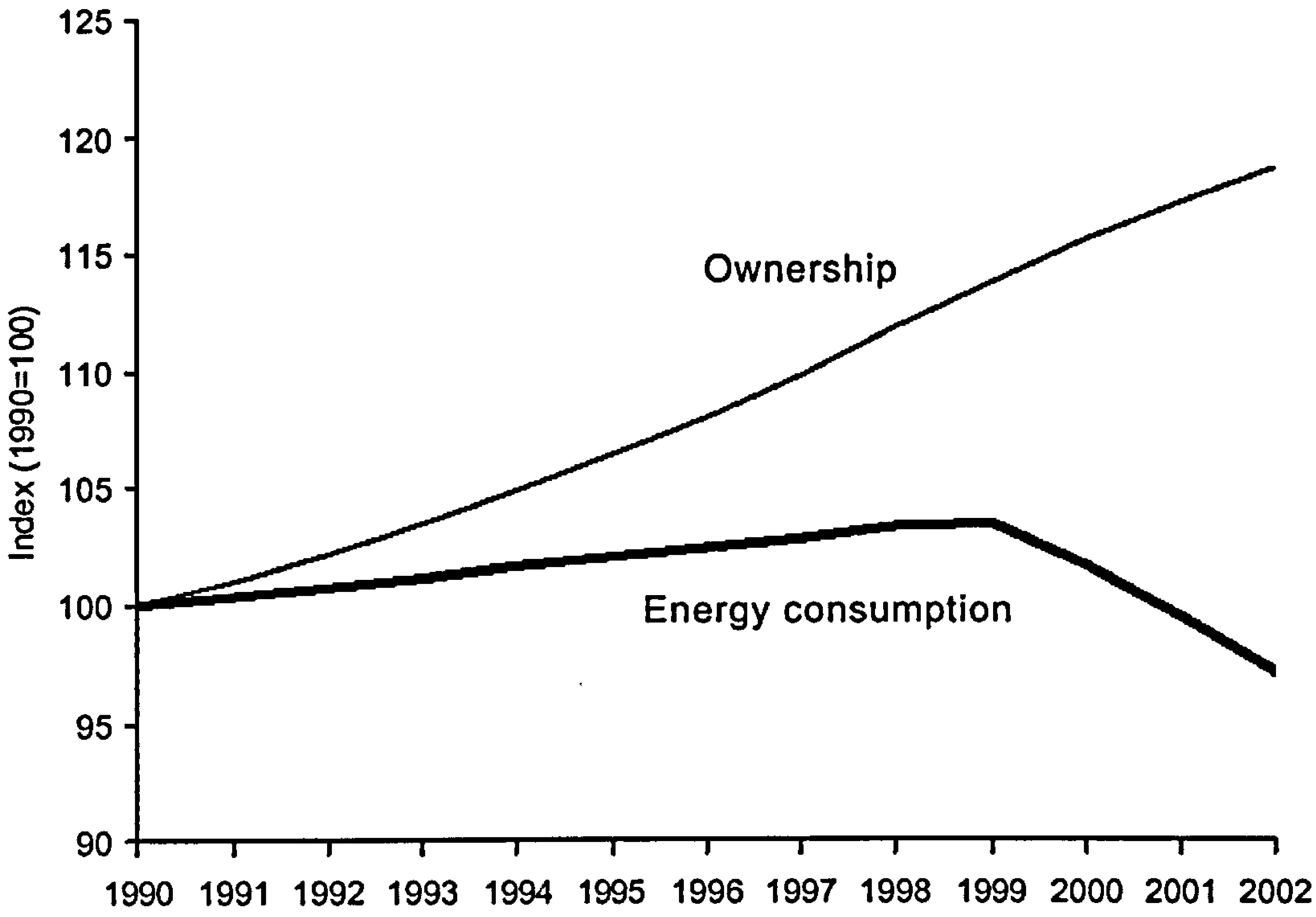


Figure 2.4. Ownership and energy consumption for cold appliances, 1990 to 2002
Source: DTI (2003)

Another issue here is the impact of technology substitution. Relating energy savings to improvements in minimum efficiency levels and greater awareness of labelling alone assumes that appliances are replaced on a like-for-like basis, but technology substitution introduces new factors that need consideration. Replacing a CRT TV with an LCD equivalent reduces power consumption by around two thirds (Baker, 2004) but that assumes that consumers will opt for a comparable screen size. There is now strong evidence that the replacement of CRTs by flat-panel TVs is leading consumers to purchase larger screen sizes, and that this is set to have a significant impact on UK domestic emissions. There are currently 63 million TV sets in the UK, most of which are CRTs, which consume 9.6 terawatt hours of electricity per year and are responsible for 1 million tones of carbon emissions. The UK Government's Market Transformation Programme (MTP) estimates that this will rise to 67 million by 2010, a mere six percent increase, but that power consumption will increase by 5.7 terawatt hours, equivalent to the output of half a coal fired power station, and lead to an increase of 700,000 tonnes of carbon emissions. The cause of this dramatic jump is simply consumers buying larger screens (Russell, 2006).

Similarly, replacing a old washing machine with a model that offers low energy use programmes is only useful if consumers use them, and replacing a cold appliance with a more efficient model only reduces energy use if the two are of a similar size or if the newer model does not incorporate new facilities, such as an ice-maker or new technologies such as 'frost-free'. Reducing energy consumption requires more than labelling and substitution, there is also a distinct need for consumers to think beyond the label and consider how much energy their new purchase is consuming in real terms compared to what it is replacing (Boardman, 2004).

However there is yet more to this debate that needs to be accounted for in studies of energy consumption by domestic appliances. The UK is one of many nations now entering the 'digital age', and the signs are that the growth in ownership and use of high-tech devices, many of which will be 'always on', will have significant implications for domestic energy consumption.

The typical household power consumption used by TVs and recording devices is expected to increase from 0.1kWh to 0.4 kWh per day as the result of the digital switchover. Using the 2001 figure for the number of households in the UK this equates to an increase in total demand of 7327 kWh per day and 2.67 million kWh per year. Although improvements in device efficiency may serve to mitigate this increase the figures serve to demonstrate how an apparently small increase in daily demand can have a significant cumulative impact on total domestic energy consumption (Karger et al., 2005).

One option for addressing this issue is to track and attempt to influence the number of these devices in use in our homes. For the time being householders may be content with receiving a digital signal to their living room entertainment cluster and transmitting data to secondary systems via an analogue connection, but this may not be an option once the analogue frequencies are sold off post-switchover. Furthermore, future energy studies may need to include how and where information is stored and accessed. At present Google and Microsoft are offering two opposing visions of this future (Reuters, 2006) but as the volume of data being accessed by households continues to increase technology ownership and use can be expected to be an increasing influence on domestic energy consumption. Even in mobile systems, where energy efficiency has been a key concern for years, reducing the consumption of one component is invariably seen as an opportunity to free up power to enhance and diversify the performance of other components (Baker, 2003). Therefore future models of domestic energy consumption need to account for the new energy demands imposed by the coming of the digital age in terms of the number and diversity of devices in use in homes, their baseline energy demands, the periods over which they are in operation and standby modes, and the rates of technological change and uptake by consumers.

2.2.7. Household Composition

The changing nature of the composition of UK households has profound implications for energy efficiency research. Research by the Office for National Statistics (Francis, 2004) has shown that the lowest per capita emissions are generated by households comprising three or more people where the head of the household is under 30, whereas the highest per capita emissions are generated by single person households where the occupant is under 30. In the UK many media reports have vilified single person households (Aune, 2006), as well as multiple occupancy households where the occupants are unrelated (for example houses shared by groups of young professionals or students) due to their environmental impact, yet ONS figures show a consistent and growing trend towards greater numbers of these households. The reasons for this trend are too complex to be covered in detail here, but even a cursory inspection of the data on changes in the UK's socio-demographic make up points to factors such as adults delaying the point at which they settle down and have children, a greater proportion of single people in the population, and an increasingly mobile workforce. The demographic shift of English households from 1971 and projected forward to 2026 is shown in Figure 2.6.

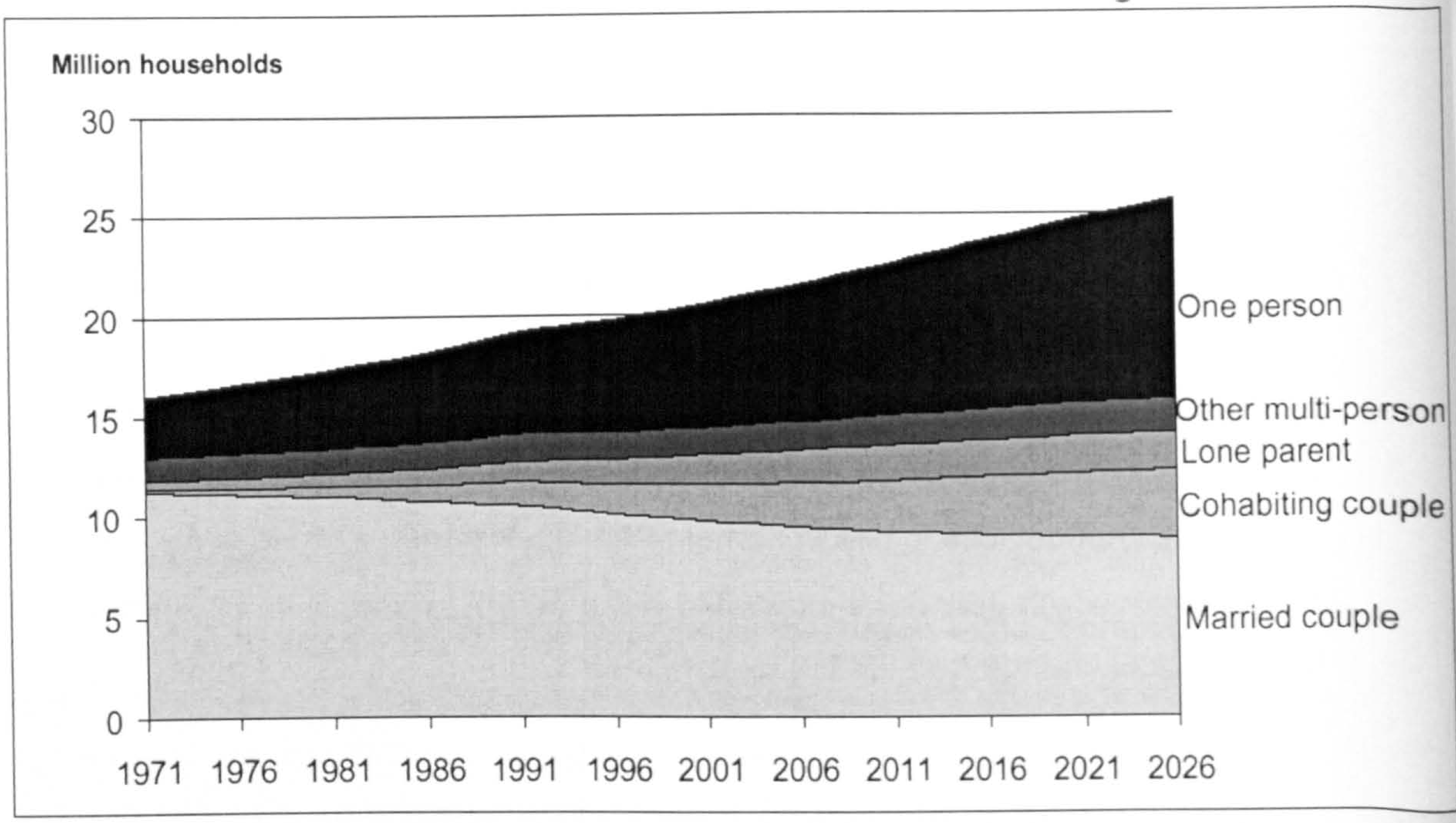


Figure 2.6. – Changing Numbers and Demographics of English Households, 1971-2026
Source: DCLG (2006)

The geographical distribution of different household types has been well researched and should be an important consideration for targeting schemes aimed at improving domestic energy efficiency, especially in inner city areas subject to urban regeneration projects.

Of the fifteen City Form study areas one (Glasgow city centre) was the subject of a high profile urban regeneration project in the mid-1990's and another (Leicester city centre) is currently under going massive redevelopment. Seo (2002) conducted a comprehensive study of the impact of urban regeneration schemes on the socio-demographic compositions of the city centres and inner city areas of Manchester and Glasgow that produced findings that appear at odds with the aims of many of these schemes, where the benefits of city centre living are being promoted as easier access to cultural and entertainment facilities. Seo found that the predominant reasons for residents choosing to live in both city centres and inner city areas were far more practical than access to culture. Top of the list for city centre dwellers was access to their place of work, and whilst this was also an important factor for inner city dwellers it was outweighed by value for money, a factor not considered important by their more affluent city centre counterparts. Both groups placed a high level of importance on being in a central location, which was also the key factor in determining satisfaction after they had moved to the areas, suggesting that access to services such as public transport networks is important in both encouraging occupants to move into cities and keeping them there. Access to cultural facilities and quality of housing and the local environment only became important after householders had moved, but even then this was still outweighed by the more practical elements.

The key difference between the two groups was a combination of factors known to reflect affluence. City centre households were more likely to be younger, white, owner-occupiers and comprised of single people or couples in white collar jobs and without children. In terms of modelling the energy used for heating and lighting these groups pose an additional problem, as their more varied and transient lifestyles mean that the traditional assumptions of daily occupancy regimes may no longer be accurate.

Similar problems relate to two other groups existing in large numbers in the City Form study areas (ONS data) – student households and retired singles and couples. Whereas the latter may have more standard occupancy regimes, both groups can be expected to have higher relative levels of disposable income. The entry of the term 'silver-surfer' into the English lexicon has come about due to a new generation of technologically-savvy retired people investing in increased amounts of high-tech goods. This is supported by Francis (2004) who found that the second highest source of emissions from over-65 households was direct emissions from energy using products.

Knowledge of household composition in terms of age and employment status should be a useful indicator of how long each dwelling is occupied for and how energy is used on a daily basis. This is noted in Blasco Lucas et al. (2001) who concluded that different household compositions, for example a family consisting of two adults and two children compared to a shared student/young professional household, can have a significant impact on the amount of energy they consume. Different household types can also be expected to place different emphases behind choosing their appliances, for example a large family has more to gain financially by opting for an energy efficient washing machine, whereas a young couple may favour better visual design or opt for a cheaper model in order to spend more on technology such as a widescreen TV.

The lowest levels of per capita emissions are generated by households comprising three or more people (including children). Although households in this group are most likely to have a household head aged 30-64 (the age group producing the highest level of emissions) the group also has the highest proportion of families, therefore total household emissions are shared between larger numbers of people.

Although it does provide a summary of emissions by fuel type by the number of occupants Francis's work does not differentiate emissions from 'energy using products' in terms of that used for heating, lighting, appliances, etc.

Household composition and socio-economic status also has and important role to play in terms of what energy efficiency improvements householders may choose to make to their homes, and the level of impact those improvements may have on reducing their fuel bills. The next section gives an overview of some of the studies carried out aimed at quantifying the impact of energy efficiency improvements and the problems encountered in trying to do so accurately across a socially and economically diverse population.

2.3. Chapter summary

This literature review has discussed the previous studies of domestic energy consumption most relevant to this thesis and provides the context in which to view the work that follows. The most important antecedent study is that of Perkins (2002). Although even this is notably different in scope the approaches used for the data analyses demonstrate the benefits of a rigorous use of techniques that are relatively simple but produce results that are statistically sound and difficult to interpret erroneously. This thesis adopts a similar approach to the data analysis but draws in other techniques that meet these criteria.

Previous work on factors influencing differences in domestic energy consumption has been covered in order to establish those for which considerable established knowledge already exists, and those that are less well understood. This has been done in order to identify those for which there is the greatest potential to yield further knowledge using the methodology described by this thesis.

Chapter 3. Survey Methodology

3.1. Introduction

This chapter discusses the design and development of the postal questionnaire, which was the approach chosen to gather the data necessary to conduct these studies.

The dwellings targeted for the study were selected to provide the largest possible samples of homogeneous built form types from within the fifteen City Form study areas. This was to enable the analysis of variables influencing consumption by controlling for built form type, and to compare their levels of influence between the samples. The built form types were also selected to be representative of the most common types of dwellings within the UK housing stock.

The likely response rate was difficult to predict although anecdotal evidence suggested that for a very detailed questionnaire such as this it might be very low. Above all, therefore the survey instrument was designed to be clear and supportive, in order to minimise the risk of cognitive overload and consequent failure to respond. A pilot survey was used to assess the likely response rate and estimate the number of dwellings that would need to be targeted to produce a dataset of acceptable size. The pilot survey was costed (Appendix 4), and the time taken to produce the questionnaire packs and the average response time were also noted. This information was used to optimise the main survey, particularly the content and format of the questionnaire, as discussed below.

3.2. Development of the questionnaire

A survey instrument was required that would enable accurate and quantifiable assessments of differences in domestic energy consumption and energy efficiency measures. Clearly there was a trade-off between the need to return sufficiently detailed data and the likely response rate. Compatibility with existing methodologies and the need to cover gaps in previous studies were also factors that led to an iterative design process. Another issue was what, if any, of the data collected by existing surveys could be obtained or approximated from other sources, principally the GIS coverages of the study areas.

The development of the methodology was strongly influenced by the work of Perkins (2002): the use of annual energy consumption data is a common factor in both studies. However, unlike Australia (the setting for Perkins' work) in the UK, the privatised utilities sector presents many obstacles to the acquisition of data. At the outset it was assumed that each company would have to be approached separately and a common format agreed for the release of data.

In order to develop the questionnaire two reviews were conducted, one on established methodologies such as BREDEM, SAP and NHER, and one on energy efficiency questionnaires used by local authorities as discussed in the following two sections.

3.2.1. Assessment of established energy survey methodologies

Following the literature review a more intensive study was made of the data requirements for several existing energy rating schemes and models: the reduced data SAP (RDSAP); the Estimating Municipal Energy for Residences using Arbitrary Levels of Data (EMERALD) model developed at the IESD based on BREDEM-8 (see Rylatt et al., 2003);National Homes Energy Rating (NHER) service's Level 0 survey; NHER Site Surveyor Level 1 for houses and bungalows (henceforth referred to simply as NHER Level 1); and the various home energy efficiency assessments available from local authorities. The data requirements and data sources for EMERALD, RDSAP, NHER Level 0 and NHER Level 1 is given in Appendix 1.

Many of the local authority assessments were not detailed enough for the envisaged study. Some were more interested in reported behaviour, which was largely ruled out for this work due to the anticipated uncertainty from subjective reporting. Although NHER Level 0 represented a good basic dataset it was expected that respondents would be able to provide a larger volume of information at a higher level of detail, probably between Level 0 and Level 1, which might be more useful in conjunction with the data to be acquired from the OS Mastermap GIS coverages, in lieu of on-site survey. The RDSAP approach - largely based on descriptive answers intended to be elicited by a qualified surveyor - was considered unlikely to transfer successfully to a postal survey instrument. The NHER Level 1 dataset appeared to be the best approximation to the level envisaged and, although some of the more detailed questions in the survey presented difficulties to adaptation for completion by non-specialists, all were retained with the exception of the sketch plan and dwelling dimensions. Most of the key questions, such as details of heating systems, were considered to be reasonable for inclusion without modification. This was facilitated by slight simplifications of the information being requested or by the provision of supplementary information in an appropriately non-technical style.

3.2.2. Review of Home Energy Efficiency Questionnaires

A review of Home Energy Efficiency Questionnaires (HEEQs) was conducted in order to identify the best features of existing HEEQs and how these might be incorporated into the pilot questionnaire in order to provide complementary information to the questions adapted from the NHER Level 1 survey. HEEQs are a common method used by councils, local authorities, and organisations such as the Energy Savings Trust to raise the awareness of householders of inefficiencies in their energy use regimes and identify simple measures to reduce their consumption.

3.2.3. Home Energy Efficiency Questionnaires in England

Every English council surveyed (by web search) offered some form of

HEEQ, either regionally or locally. Obtaining copies of every HEEQ in use was infeasible in the time available, however most of those listed here as being in use by local authorities were found to be of a similar standardized content and format. Table 3.1 lists all those reviewed, the sources for each are given in the bibliography. Formats varied from 'download, print and post', to 'request by e-mail', to fully online, most with the option of receiving a printed copy by post. It was not possible to assess the level of access to HEEQs off-line or to assess the number of councils, if any, not offering some form of energy advice on their websites.

Table 3.1. – List of Home Energy Efficiency Questionnaires reviewed

Home Energy Efficiency Questionnaires
UK HEEQs
Anglia East online HEEQ
Bristol & Somerset Energy Efficiency Advice Centre online HEEQ
Chesterfield Council online HEEQ
Islington and Hillingdon Councils online HEEQ
Leicestershire/Northamptonshire Energy Efficiency Advice Centre online HEEQ
Oxford City Council postal HEEQ
Peterborough Council online HEEQ
St Albans online HEEQ
Non-UK HEEQs
Energy Depot online HEEQ, USA
EnergyStar online HEEQ, USA
Powerquest online HEEQ for Hawaii, USA
SDGE online HEEQ, USA
"Uw wonung/Uw persoon", Belgium (not limited to domestic energy efficiency)

In the UK a semi-standardised form is in use by many councils, consisting of tick-box questions on occupancy, built form, heating and hot water, lighting, and recent changes to the property. Councils such as Islington Council (2004) and Hillingdon use a simple black and white format whereas others, such as Chesterfield Council (2004) and Oxford Council (2004) have developed this format into a full colour leaflet.

In the case of Leicester the local council website links directly to the Leicestershire/Northamptonshire Energy Efficiency Advice Centre (2004) which offers an online home energy check based on the semi-standard format. This is also one of the cases where it appears a centralised service is being used, other examples of which are the Bristol & Somerset Energy Efficiency Advice Centre (2004) form hosted by the Croydon Energy Network and North West London (2004) website which links back to the Islington site. The former was unusual in containing photos of walls and central and water heating controls to clarify the information being requested. However, in common with Leicester, the surveys were designed to be completed online, with details of local energy advice centres listed on linked pages.

One of the most comprehensive energy advice and HEEQ pages is Bracknell Forest Borough Council (2004) where a questionnaire based on the semi-standard format was available in both online and 'download and print' formats with relevant local contact details.

Peterborough Council's (2004) online HEEQ was the one of only two found to make explicit mention of major appliances, asking about ownership of fridges, freezers, washing machines, tumble dryers and dishwashers, and also their age. The other was Anglia East (2004).

Another usual finding, this time in 'download-and-print' portable document format, was the St Albans (2004) HEEQ, which included supplementary information intended to help respondents answer it.

3.2.4. Other HEEQs

To provide a comparison with UK energy surveys several other HEEQs were found online, mainly from the US. By far the most extensive and detailed were published by the US companies EnergyDepot (2004) and SDGE_(2004) both of which dwarfed any of those from the UK. Although obviously US-orientated (for example having sections on pools, spas and waterbeds) both contained sections on fridges/freezers, kitchen appliances, laundry facilities, and many other household appliances. They also request much more detailed information on appliances and behavioural patterns, especially with regard to appliance use and occupant behaviour, for example '*how many times a week do you hand wash your dishes?*'.

Two of the four US HEEQs requested energy billing data. The US's EnergyStar programme (2004) hosts a home energy performance calculator on its website which requests information on fuel type, conditioned floor area, occupancy, geographic location, fuel consumption and fuel cost. It then gives a result comparing the dwelling's energy efficiency to the US average and suggests improvements. This is a basic method for relating fuel use to conditioned floor area and allows for the influence of occupants and latitude.

The second, from Powerquest, Hawaii (2004) was more extensive and by far the most behaviourally-orientated of all the HEEQs surveyed. Respondents enter their monthly electricity bill and whether or not their home is fitted with photovoltaics followed by questions on water heating, major appliances and lighting. The section on water heating covers heating type, insulation and placement, but also water temperature, whether respondents turn taps off whilst washing dishes etc, and how long on average each family member spends in the shower. Major appliances covers the following: condition of door seals; whether respondents consult consumer buying guides; how long fridge/freezer doors are left open; if pots and pans used to cook food are appropriately sized and whether lids are used; dishwasher, dryer and oven use; condition of coils on fridges/freezers; and how often cold water is used to wash clothes. The final section on lighting assesses the use of low wattage, fluorescent, and compact fluorescent bulbs, as well as the number of bulbs used to achieve the desired level of lighting.

Although this HEEQ has obviously been tailored for a very specific audience (island-dwellers already using many greener technologies) some questions were worth considering for the energy questionnaire.

The Belgian (2004) questionnaire "Uw wonung/Uw persoon", also in used in France, Germany and the Netherlands, covers both dwellings and people, the latter half of which will not be discussed here. The questions on built form are very similar to those commonly used in UK surveys. Additional questions cover rent rates; utility access; condition of dwelling; conveniences; and access to local amenities.

3.2.5. Conclusions from the review of HEEQs

One significant point that has arisen from this survey of questionnaires was that the level of detail requested from respondents is generally in line with that sought by NHER Level 1. This was important evidence that the data requirements for existing surveys were at a similar level of detail. However, it was still necessary to bear in mind that the respondents would be self-selecting, and therefore the number of targeted dwellings would have to be sufficient to allow for a low response rate.

The questionnaires surveyed differed considerably in length. The shortest, such as the Islington and Hillingdon, were presented on one A4 sheet, with questions laid out clearly but closely packed. In the UK the longest of the 'print and post' questionnaires (Bracknell Forest) extended to five sides (without any supplementary information) whilst the 'online only' ones reached seven or more. In contrast the two highly detailed US questionnaires, both in 'print and post' format, both run to fourteen sides with minimal additional information.

Condensing a survey to one sheet may improve response rates if respondents aren't faced with a multi-page booklet, but this risks compromising the format by reducing text size and the space available for defining any potentially ambiguous terminology. Taking the opposite approach, a more sparsely presented questionnaire over many pages may be easier on the eye but may also deter respondents by its perceived length.

Finally the survey raised the issue of which, if any, questions on occupant behaviour relevant to energy use should be included. Behavioural questions risk being too subjective, for example 'do you always turn off lights when leaving a lit room?' is arguably too open to interpretation and therefore respondent bias. However, others have value in terms of being directly quantifiable and less likely to be open to bias, for example requesting the number of showers and baths taken per week.

Following the completion of this review the NHER Level 1 survey form was revisited in order to consider how best to adapt and format the questions for use in a postal questionnaire, and which additional questions to include.

The NHER form used as a basis for the questionnaire can be found in Appendix 2 and the pilot questionnaire is included in Appendix 3.

3.3. Use of NHER Level 1 as a basis for the questionnaire

In some cases the level of detailed information to be requested from respondents in order to fulfil the data requirements for NHER Level 1 survey form was problematic. An example of this is section 3 of the survey form, where respondents are asked the age of their dwelling. In other cases, e.g. windows and glazing, attempts were made to expand on the level of data being sought.

The later sections of the questionnaire contain most of the questions additional to NHER Level 1, these include the questions on appliance ownership and use and those requesting socio-economic information. These sections were largely developed from scratch, but based on similar questions used in published studies and the results of the review of HEEQs.

Obviously it would have been completely unreasonable to request dimensional dwelling data from respondents as the likely completion rate would be small and the data collected would not be very reliable. Therefore the options to request dwelling dimensions and include the sketch plan used in the NHER Level 1 survey form was rejected, although these represent the only complete omission of questions from the form. However, having access to the Ordnance

Survey (OS) MasterMap buildings layer meant that fairly accurate information could be readily obtained for each building polygon (to within about 10% accuracy). Therefore in most cases the the building floor area could be estimated from this and a cruder estimate of total floor area could be obtained by multiplying by the number of storeys, where this was reported. These estimates of floor area were extracted from the GIS coverages using MapInfo versions 7 and 7.5.

As a trade-off with the likely response rate a limit of four sides (later extended to five to improve the formatting) was set as a goal, and the questionnaire was developed with the aim of respondents being able to complete it in ten to fifteen minutes.

3.4. Obtaining energy consumption data from respondents to the pilot questionnaire

At this early stage of the work it was envisaged that electricity and gas consumption data could be obtained in one of several ways. Ideally this would be by respondents signing a mandate form that would be acceptable as proof of permission by their suppliers. With this in mind approaches were made to several major utility companies, who on initial contact seemed amenable to providing the data. Without any definite agreements at this stage the permission slip used for the pilot project (see Appendix 5) also gave the respondents the option to return copies of utility bills with their questionnaires, and to provide contact details for arranging a visit to read their meters. The slip and cover letter for the questionnaire were developed in consultation with the legal department at the university to ensure that they complied with the Data Protection Act and to be acceptable as proof of permission to release the data.

The following sub-sections provide a summary of the pilot questionnaire and, where relevant, how it relates to NHER Level 1.

3.5. Structure of the Pilot Questionnaire

Type of dwelling

As the NHER Level 1 survey form is designed for use for houses and bungalows the types of built form listed needed to be extended to include all those that are expected to be found across the fifteen study areas. Therefore maisonettes, flats and tenements were added, with an additional question asking, in the case of residents of flats or tenements, the floor of the dwelling and the total number of habitable (i.e. heated) floors in the building.

Under NHER Level 1 terraces are split into 'mid', 'end' and 'with passage'. The question of whether or not a terrace has a passageway was deemed not to be mutually exclusive of the former two options and therefore a box for 'with passageway' was provided as an additional option, rather than as a specific choice.

The categories 'back-back (mid)' and 'back-back (end)' were dropped as it was felt that these could be too easily confused with certain types of terrace and that, if necessary, such relatively unusual examples of built form could be identified from GIS or walk-by surveying.

Tenure

This is not requested under NHER Level 1 but was included due to the evidence from Boardman (2004) that less affluent households often live in less insulated dwellings, which can be expected to include those in council, housing association and other types of rented properties. The categories used are the same as for the 'Living in Britain' report (Walker et al., 2001) and could be a suitable proxy for the more detailed data on insulation levels collected by NHER.

Privately rented properties were split into 'privately rented, fully furnished' and 'privately rented, part or unfurnished' in an attempt to further differentiate between the number (if any) of major appliances supplied by the landlord and those owned by the occupants, and to use as an inference on the level of condition to which the dwelling is maintained by the landlord.

In light of the trend towards out-sourcing of university managed accommodation to private companies this category was redefined as including all hall-type properties maintained by, or on behalf of, a university for the sole purpose of housing students.

Dwelling age

The NHER survey splits this into nine age bands according to the building regulations in force at the time of the dwelling's construction (which gives an indication of the level of energy efficiency embodied in the design) one of which is as small as four years. Although this risks inducing an element of error from misreporting the differentiation is important. Suspect results can be cross-checked with information from the walk-by surveys, secondary sources and local knowledge, albeit that this is a much easier task in the study areas containing higher levels of homogeneous built form than the mixed-use city centres. It can also serve as an indicator of the general level or respondent accuracy and therefore the question was included unchanged.

Living space details

This section was adapted from the dwelling dimensions section of the survey form to provide essential details, such as the presence of a basement or cellar without requesting the exact dimensions.

An additional question asking for the number of bedrooms was included as persons per bedroom (ppb) is a recognised indicator of density.

Walls and Roof

This is substantially the same as NHER Level 1, although questions relating to any extension of the building were grouped together separately in section 11.

Whilst asking for the thickness of a dwelling's loft insulation may be considered an unreasonable request, the question was retained as this information has potential value. A 'don't know' box was added with the intention of not letting this question discourage potential respondents from completing the rest of the form.

Windows and Glazing

At NHER Level 1 the surveyor is required to merely describe frames and glazing by percentages per dwelling. It was felt that if such estimates were provided by respondents the results would be too arbitrary and that a key aspect of the role of glazing in energy efficiency, its orientation, was not included. The solution arrived at for the pilot questionnaire was to provide a table requesting the majority of frames and glazing by its orientation in terms of the front, back, and left and right sides of the dwelling, and then ask respondents to name the road their house faces (avoiding the assumption that this equates to the same road as the address). The actual (N/S/E/W) orientation of the windows could then be derived from GIS.

Main heating

Due to the known significance of heating as a factor in household energy consumption it was important to make this section as detailed as possible. Although the questions used are very similar to those on the NHER survey form, the format was substantially altered by grouping heating systems by type and producing a layout which makes it clear to respondents what information is being requested.

It was uncertain whether or not owners of dwellings heated by radiator systems would be likely to check the make, model and number of their boiler, however, it was decided that the number of returns for this question would be used to decide whether or not to omit it from the extended work.

Heading controls

A separate subsection containing these questions was introduced to produce a clearer layout and avoided the risk of respondents overlooking the questions in what had become a very large section.

Secondary heating

This is a much more extensive section than that used under NHER Level 1. The section was designed to request more detailed information using questions that would be easy for respondents to complete and return information that would provide a greater insight into respondents' use of additional heating in their dwellings.

The basic NHER categories form the backbone of the section, but electric heaters are split into 'fixed to wall' and 'portable', the latter can be expected to be generally less efficient but in less frequent use. As a caveat to this assumption the question of the number of portable heaters in regular use during cold weather was added. Respondents were also asked where in their dwelling the secondary heating is used, thus splitting the 'extent of heating' question used in NHER Level 1. This was intended to provide information that would indicate the areas of respondents' dwellings that were not adequately heated by their main heating system. However, it could also be indicative of households deliberately heating specific rooms when there is no need for the main system to be in operation.

Water heating

This was one of the sections where the decision to supply guidance notes meant that clarifications and definitions could be provided in a form that kept the layout of the questionnaire free of an overly large amount of descriptive text.

For boiler size, based on published NHER criteria, 'small' was defined as being able to provide enough hot water to fill a bath and as occurring primarily in flats and small homes, whereas a distinction in height based on standard dimensions (of above or below 5ft/150cm) was provided to differentiate between 'medium' and 'large'.

A question was added asking when the boiler was last serviced as an indicator of how well householders maintain their water heating systems.

Extension details

This is a grouping together of the age, and walls and roof construction information as a separate section and was done to improve the overall format of the questionnaire.

Conservatories

Under NHER Level 1 conservatories are covered in comparatively little detail to other parts of a dwelling. Therefore this section was developed to include questions on heating and cooling methods and regimes which are not covered. These were included with the aim of furthering the understanding of how people use conservatories.

Ventilation and cooling

Whilst NHER Level 1 questions only whether householders have mechanical ventilation installed, this question was extended to become a section in its own right. Additionally to ownership it questioned where and how they used it, and whether they intended to install it in the future.

Energy efficient lighting

This is a modification of the NHER question, which requests the percentage of energy efficient lightbulbs in use. The question asked for the actual number of such bulbs in use as the primary light source in a room (0 to >5) and which rooms they were used in.

Appliance Ownership and Use

This section was developed specifically for the questionnaire, based on the results of previous studies and also incorporates the NHER question relating to cooker type.

A table was deemed the best option for collecting information on the ownership (including 'ownership' as part of a rented property) purchase date, and energy efficiency ratings of nine key appliances. This was the result of numerous drafts where this question had been split up being deemed to confusing both for respondents to answer, but it also simplified the recording of responses.

TV and PC ownership was questioned separately, along with some other key questions relating to the major appliances.

Access to the internet via a dial-up or broadband connection was included as a recognised indicator of household affluence, and as an indicator of the household's level of access to information.

Additional Information

This section covers energy supplied from off-peak and 'green' tariffs; additional cladding; energy efficiency grants; solar panels; and frequency of bathing/showering.

Reasons given for energy efficiency improvements

These two questions, regarding why householders may have chosen to implement energy efficiency measures and what prompted them to do so, are additional questions not found in previously published studies.

Household details

This is the main section of the questionnaire used to gain socio-demographic information, which comprises the bulk of the explanatory variables used to analyse the results by household composition.

Address

There was a question over whether or not to include this section, given that the address of a household is included in the form requesting access to energy consumption data. It was initially included at the head of the questionnaire then subsequently omitted before it was decided that the overriding consideration was that any returned forms should be able to be linked to a specific address, whether or not the respondent also filled in the permission slip.

3.6. Selection of the Birstall study area for the pilot project

An exhaustive study of all fifteen study areas and sub-areas was conducted using the GIS coverages for each area and local knowledge from the consortium participants, supported where possible by site visits. The study was used to identify those areas composed of large numbers of dwellings of homogeneous built form at which to target the questionnaire. This aim ruled out the use of the five city centre areas, leaving the ten 'between' and 'city edge' areas. Suitable groups were found in two of the Leicester study areas, Clarendon Park and Birstall, and the Pollockshields area of Glasgow. Areas with more mixed dwellings were identified in the Dalry and North East Corstorphine areas of Edinburgh and in the Fulwood area of Sheffield. The latter showed the most potential for further work due to the fact that the area was almost entirely residential with very few commercial or mixed-use buildings that could lead to targeting errors when the addresses were extracted from the coverages.

Birstall was deemed to be most appropriate for the pilot work for a number of reasons. Opting for one of the Leicester study areas was most appropriate for the pilot work as any suspect results, for example incorrect reporting of dwelling ages, could be easily clarified with site visits. This left a choice of Birstall or Clarendon Park, both of which contained groups of dwellings in sufficient numbers to satisfy the aim of targeting for homogeneity of built form. Clarendon

Park is mainly composed of the brick terraces that are characteristic of the built form found throughout many areas of Leicester, whereas Birstall is composed largely of groups of semi-detached properties built in the 1920's and 30's and 1950's and 60's.

At this point it was necessary to consider if either area might be more appropriate for targeting as part of the extended work. Although Birstall is unique in being the only one of the fifteen study areas that can be classified as a typical 'leafy suburb' the composition of its built form reflects its history as a village that has been absorbed into the Leicester conurbation, rather than being a suburb grown out of the city itself. This difference in character and the fact that other study areas contained suitable groups of semis and detached properties meant Birstall lent itself more to the pilot work, leaving the Clarendon Park terraces available as more typical of Leicester's built form and having greater potential for studying as part of the extended work.

As a result Birstall was selected for the pilot work, and using the GIS coverage in combination with observations from site visits a group of 373 1920's-1930's semi-detached dwellings in the north and west of the area was ring-fenced for the study. This area is shown in Figure 3.1.

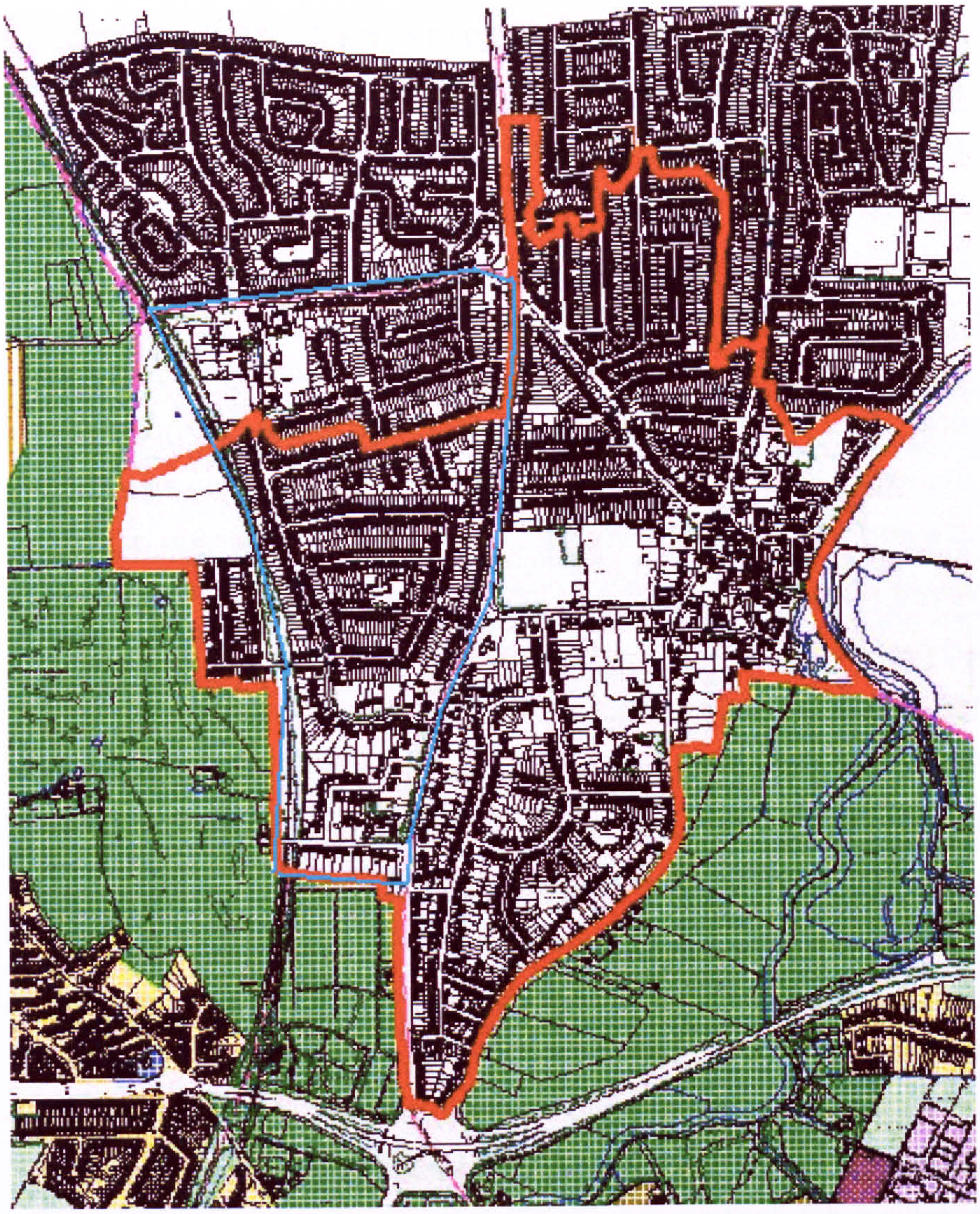


Figure 3.1. – The Birstall pilot project study area
The City Form study area boundary is shown in red, the area targeted for the pilot project is shown in light blue.

3.7. Results of the Birstall pilot project and revision of the questionnaire

Due to the ongoing uncertainties over the acquisition of household energy consumption data the primary purpose of analysing the results from the pilot study was to provide an assessment of the likely response rate to the extension of the survey work, and the level of information that could be expected to be gained from each questionnaire. This section summarises the data obtained from the pilot questionnaire and details the revisions made to develop the final questionnaire used for the extended survey work.

Selection of homogeneous dwellings

Despite the low response rate (42 out of 373) for the pilot study important lessons were learned and used to inform the redesign of the questionnaire in preparation for the extended work. The aim of targeting homogeneous dwellings, in this case 1950's and 1960's semis identified using the GIS coverage of Birstall, was largely achieved (Tables 3.2 and 3.4). Only 7 of the respondents reported living in detached properties, and 31 respondents reported their dwellings as falling into the 1950-65 construction bracket. 41 of the 42 were two storey properties, no respondents reported having a cellar, although 2 had basements, and all had brick walls. Some confusion seems to have arisen over the number of rooms, with respondents reporting anywhere between 1 and 13. The confusion may have been due to also asking for the number of bedrooms and so this was further clarified in the revised document. The only other point worth noting was the 4 no responses to roof type (the other 38 reporting pitched roofs) and as such the word 'sloping' was added to the questionnaire. These results were taken as an indication that the method of selection would be adequate for the extension of the work.

Table 3.2. Dwelling type

Dwelling type	
Detached	Semi-Detached
7	35

Tenure

Previous research has shown that owner-occupiers know more about the construction of their dwellings than those in other categories of tenure and tend to live in more energy efficient homes. Although the selection methodology does not allow for targeting based on tenure only one of the respondents reported living in a rented property. Surprisingly in this case the respondents left only 5 questions uncompleted out of a total of 68[1], compared to an average of 6.24, but as this is a single figure from a relatively small sample size it should not be viewed as significant. Therefore even if it were possible to target by tenure an inherent trade off exists between testing this assertion and the expected level of completeness of the returned questionnaires.

Table 3.3. Dwelling tenure

Tenure		
Owner occupied, owned outright	Owner occupied, with mortgage	Privately rented, part or unfurnished
21	20	1

Insulation

Only 5 no responses were returned for the question on wall insulation and only 6 respondents failed to give a thickness for their loft insulation, of which a mere 2 left both uncompleted. As there was no indication amongst the responses that this was due to anything other than lack of knowledge these questions were deemed acceptable for use as is in the revised questionnaire (Table 3.4.).

[1] This is a slightly arbitrary figure as many questions follow on directly from others, and therefore need to be considered as a group. In the case of radiator systems for main heating the question was considered complete if the respondent had gone as far as specifying boiler type.

Table 3.4. Dwelling Construction

Dwelling Construction				
Dwelling constructed	1900-29	1930-49	1950-65	No response
	2	31	8	1
No. Floors	1 Floor	2 Floors		
	1	41		
No. Bedrooms	3 bed	4 bed	5 bed	
	36	4	2	
Basement?	Yes	No	No response	
	2	39	1	
Cellar?	Yes	No	No response	
	0	40	2	
Wall type	Brick			
	42			
Insulation	Solid wall	Cavity wall	Filled cavity	No response
	21	10	6	5
Roof type	Pitched	Flat	No response	
	38	0	4	
Extension?	Yes	No / No response*		
	26	16		
Conservatory?	Yes	No / No response*		
	11	31		
*Due to the omission of a Yes/No box at the start of these sections it is unclear whether or not the section was not filled in to indicate a 'No' or should count as a 'No response'				

Windows and glazing

The issue of what information to obtain and how to obtain it was the subject of much discussion during the development of the pilot questionnaire. Numerous options were considered and after several revisions a table was devised for respondents to fill in the number and type of their windows and the results show that all completed this question, although two did not specify the number of windows of each type. Whilst this is a method of returning a similar level of detail as can be obtained from a sketch plan the nature of the data made it difficult to code in any manner that could provide a quantifiable and meaningful input to either statistical analysis or modelling. Therefore in the revised questionnaire this has been reduced to simply questioning the glazing and frame type of the majority of windows in a dwelling. Although this risked inducing a higher level of uncertainty than the more detailed information acquired from the pilot questionnaire it seemed doubtful that this higher level of detail would have any practical application as part of the data analysis, and it is unlikely that any significant benefit could be gained by acquiring it.

Main heating and heating controls

The results to this section of questions proved to be the most positive in terms of demonstrating that a relatively high level of detail can be obtained from non-specialists. As noted previously, in the case of dwellings with radiator systems this question was deemed as being completed if the respondent had gone as far as specifying boiler type, and of those 40 with radiator systems only 4 failed to complete the question to this extent, 2 of whom gave their boiler model. 15 of the remaining 36 also reported boiler model. Only 2 respondents ticked more than one form of heating as their main heating type, but only 12 of the 40 reported whether or not their radiators were fitted with thermostatic radiator valves. A similar number of no responses (11 out of 42) was obtained for the question on the extent of main heating. In hindsight the first problem was the poor structuring of the whole section, and the latter two due to poor formatting of the question itself (see table 3.5). Both of these problems were addressed by the reformatting of the revised questionnaire, (see later).

For main heating other than boiler/radiator systems it was impossible to draw any conclusions as to whether or not changes needed to be made, however as these questions are less detailed there seemed to be no need to make substantial changes.

Table 3.5. Main heating systems

Main Heating Systems						
Type	Gas boiler with radiators	Storage Heaters	Hot water underfloor heating	Other	No response	
	35	2*	2**	1	1	
Boiler type (out of 39 responses)	Conventional	Condensing	Combi	Condensing and Combi	Back boiler	No response
	17	4	8	1	5	
'Boiler type' completed (out of 39)	Yes	No				
	19	20				
Thermostatic radiator valves (out of 39)	Yes	No	No response			
	18	7	14			
Extent of main heating	All/almost all rooms	Living/dining areas only	No response			
	30	1	11			
Heating system controls	None	Clock/Timer	Digital	No response		
	1	18	21	2		
Thermostat?	Yes	No	No response			
	20	18	4			
Zoned heating?	Yes	No	No response			
	6	25	11			

*One response ticked along with boiler/radiator system
**One response ticked along with storage heaters, one with boiler/radiator system

Secondary heating

As with main heating most respondents completed these questions adequately for the purposes of the study. Only 1 no response was obtained for type of secondary heating, and only 4 each for use of portable electric heaters and uses of secondary heating. These results suggested no significant changes needed to be made (Table 3.6).

Table 3.6. Secondary heating systems

Secondary Heating Systems							
Type (not limited to 42 responses)	Gas fire/room heater	Gas fire open to chimney	Gas fire (flued)	Solid fuel open fire	Fixed electric heaters	No other heating	No response
	18	14	3	7	3	1	1
Portable electric heaters	Yes	No	No response				
	7	27	4				
Use of secondary heating (not limited to 42)	Living/Dining room(s)	Bedroom(s)	Kitchen	Bathroom	Other areas	No response*	
	30	3	5	3	5	4	
*No response indicates that the respondent did not tick any of the 'heating used' boxes and did not tick the Yes/No box for portable heaters							

Water heating

Table 3.7. Water heating systems

Water Heating Systems						
Type (not limited to 42 responses)	Single immersion	Dual immersion	Gas instant single point	Gas instant multi-point	From boiler / main heating system	No response
	6	4	1	1	33	1
Boiler serviced	Within the last year	Over a year ago	No response			
	25	11	6			
Boiler age	Less than 10 years	More than 10 years	Don't know	No response		
	15	8	1	18		
Cylinder size	None	Small	Medium	Large	Not applicable	No response
	1	1	23	2	1	14
Cylinder jacket	None	Spray foam	Loose-fitting	Don't know	Not applicable	No response
	2	14	13	2	2	9

Similar levels of completeness were returned for the questions asking for the type of water heating installed and when the boiler was last serviced, however almost half of respondents failed to complete the question on boiler age (despite the inclusion of a 'don't know' option) 14 no responses were returned for cylinder size, and 9 for type of cylinder jacket. The former question did not include a 'don't know' option whereas although the latter did, only 2 respondents ticked this box (Table 3.7). The omission of the option was unintended, but the results suggested that in these cases it is more difficult to attribute the no responses simply to formatting. The most feasible option to try and improve the number of responses to this question was to improve the relevant section of the guidance notes.

Extensions

In hindsight there was a glaring omission in this section – the lack of a question asking whether or not the dwelling had been extended (Table 3.4). As such the 18 respondents who did not complete any question in this section were assumed not to have one, although the level of dwelling homogeneity suggests otherwise. This was remedied and improved on in the revised version by adding both a 'yes/no' question and a question asking for the type of extension. In addition it was noted that, for many older extensions, this section simply repeats earlier questions.

Of the 23 reporting extension details 13 left one or more questions unanswered. As unnecessary repetition of questions may be a factor in reducing response rate a preamble was added to this section telling respondents that they need not complete the questions on extension construction where this did not differ from the rest of the dwelling.

Conservatories

As with the section on extensions the lack of an initial 'yes/no' question meant that it was impossible to be certain if any of the 31 respondents who did not complete any of the questions did in fact have conservatories, and this was corrected for in the revised version.

As a result of the low response rate (see table 3.8) the questions in this section were reduced to simply covering glazing type and whether or not the respondents heat their conservatories during cold weather.

Table 3.8. - Conservatories

Conservatories (out of 11 responses)				
Location	Back	Side		
	9	2		
Glazing	Single	Double	Other	No response
	1	8	1	1
Heating regime	Routine occupancy	Low level	Not heated	No response
	5	1	4	1
Form of heating	None*	Central heating radiators	Fixed electric heater	Portable electric heater
	2	4	1	4
Form of cooling	Open doors and windows	Portable electric cooling	Fixed electric cooling	No response
	8	1	1	1
Use of electric cooling	Only in very hot weather	Frequently in warm weather	Not applicable	No response
	1	1	8	1
*Both were non-responses where the respondent had ticked 'not heated' in the previous question				

Ventilation and cooling

This first question in this section covered the number of open chimneys, to which only 5 no responses were returned. The question was included here as there seemed no natural place for it elsewhere, but under the revised format it was possible to make it more obviously a question in its own right.

This section was also the only one to include questions on intended behaviour as regards future dwelling improvements, i.e. the intention to install electric cooling, type of cooling, where it would be used, and how often it might be used. The aim here was to record some tentative results on the future take-up of electric cooling and thereby infer how this might effect domestic energy consumption, however 27 respondents answered 'no intention' and a further 11 did not respond (Table 3.9). Therefore these questions were dropped from the revised questionnaire with the intention of improving the response rate by saving time and reducing the overall number of questions.

Table 3.9. Ventilation and cooling

Ventilation and Cooling					
No. open chimneys	0	1	2	3	No response
	3	15	18	1	5
Mechanical ventilation?	Yes	No	No response		
	6	29	7		
Intention to install electric cooling	No intention to install	May install in future	Already have it	No response	
	27	3	1	11	
Only two results were obtained for the remainder of this section					

Energy saving lightbulbs

Palmer (1998) showed that the use of energy efficient light bulbs is a good indicator of overall household energy efficiency. Only 5 respondents failed to complete this section (one of whom reported the number in use) and of the 37 that did 12 reported using 5 or more as the main form of lighting in rooms in their dwellings. If '5 or more' is recorded as 6, then the average number of energy saving bulbs used as the main form of lighting in rooms in our respondents' homes was 3.68, compared to an average of 3-4 in use across the EU and 3.0 in the UK (Palmer, 1998 figure, not specified as main form of lighting). Whilst this figure is consistent with the previous research it should be noted that the DELight figure for the percentage of households owning energy efficient bulbs in 1998 was a mere 23%, compared to 76% for our respondents (assuming the no responses indicate no ownership).

Due to the unexpectedly high number of respondents ticking the '5 or more' box (12 in total) this was changed to 'more than 5 (state number)' in the revised questionnaire in order to produce a more accurate average, and thereby determine how much this figure may have changed since 1998. The rest of the section was left unchanged.

Table 3.10. - Energy efficient light bulbs

Energy Efficient Lightbulbs								
EEBs used as main light source in: (not limited to 38 responses)	Living room	Dining room	Bedroom(s)	Kitchen	Bathroom(s)	Other area(s)	No response*	Not applicable **
	21	13	17	12	8	19	6	2
No. EEBs in use	0	1	2	3	4	5	>5	No response
	5***	2	5	3	7	3	12	5

*Indicates respondent had left entire section blank
**2 respondents indicated not using any EEBs
***Includes 3 respondents who ticked boxes in the previous question

Appliances

The development of this section represented the greatest departure from the basic structure and content of the NHER Level 1 survey form. The section was designed with the intention of being able to further elucidate on the work of Mansouri (1996) in assessing the impact of appliance ownership and use on domestic energy consumption, and the extent to which product labelling has contributed to overall improvements in domestic energy efficiency. The basic results are given in table 3.11.

Unfortunately the table designed to question whether respondents owned a particular appliance or combination of appliances (9 categories in total) whether or not they knew when it was purchased and whether or not they knew its energy efficiency, returned some of the most disappointing results. Whilst over half knew the year their appliances were purchased (57% average across all appliances and all respondents owning them) very few who had purchased their appliances post-1995 knew their energy efficiency ratings (5 out of 22 for washing machines, 3 or less for all other categories, which does not account for an individual reporting ratings for more than one appliance). Sadly the small number of responses made even this analysis meaningless. Nevertheless, the importance of this section to the wider goals of the research meant that the questions were still included in the revised questionnaire, albeit with the new format, an option to record the ownership of multiple appliances of the same type, and with microwaves falling into a separate group of questions.

Table 3.11. Appliances

Appliances						
Washing machine connected to hot water supply?	Yes	No	Don't know	No response		
	26	9	6	1		
'Frost free' freezer	Yes	No	Don't know	No response		
	15	22	3	2		
No. TVs owned and in regular use	1	2	3	4	5	No response
	9	13	12	4	2	2
No. PCs owned	0	1	2	3	No response	
	5	25	6	2	3	
Internet access - dial up	Yes	No	No response			
	14	23	2			
Internet access - broadband	Yes	No	No response			
	19	19	2			
Cooker type	Gas	Electric	Gas hob & electric oven	Gas kitchen range		
	19	6	16	1		

The remainder of the questions in this section all returned acceptable results, with no individual question returning more than 6 no responses. Respondents were willing to report what type of cooker they owned (100% response) but less willing to report the number of times a week they use wet appliances. These questions were left unchanged in the revised version, with the question on TV ownership expanded to include maximum screen size and technology and an additional question on the ownership of set-top boxes, which are expected to have a significant impact on UK domestic energy consumption (see literature review section 2.2.6).

In addition respondents were provided with space to report multiple ownership of any of the appliances in question, and ownership of other always on appliances that are high energy users.

Miscellaneous information

Table 3.12. Miscellaneous Information

Miscellaneous Information							
No. responses to Baths/Showers question	Response	No response					
	37	5*					
Off-peak tariff?	Yes	No	No response				
	21	15	6				
Green tariff	Yes	No	No response				
	1	33	8				
Additional boarding / cladding	Yes	No	No response				
	8	30	4				
Internal or external (out of 8)	Internal	External	No response				
	5	2	1				
Energy efficiency grant	Yes**	No	No response				
	10	24	5				
Reason for energy efficiency improvements (not limited to 42)	Lower energy bills	Help the environment	Home improvement	Other	No. not applicable ***	No. no responses ****	
	23	7	7	0	10	2	
Prompt for improving energy efficiency (not limited to 42)	Advice from council	Visit to energy efficiency centre	Adverts on TV	Word of Mouth	Other	No. not applicable***	No. no responses ****
	4	0	4	7	10	10	2

*Includes 1 respondent who entered 0 for both
**All respondents to this question stated what their grants were for
***Includes non-responses from those who stated they had not received an energy efficiency grant
****Both respondents had not answered the energy efficiency grant question. One reported using an energy efficient bulb (but did not give a location) the other did not enter a response in that section

This section was also completed by almost all respondents (Table 3.12). Only 4 declined to report the number of baths and showers taken weekly by their household, although some of the figures given did seem somewhat high for the number of occupants. Respondents who reported they had received grants to make improvements to the energy efficiency of their dwellings were particularly forthcoming, with all 10 stating what the grant was for. In the follow-up question on prompts for making energy efficiency improvements 10 of the 17 who had ticked the 'other' box gave additional information. The question asking why these improvements were made also returned a high level of completeness. Therefore no changes other than formatting were made to these questions.

Four more questions were added regarding energy efficiency grants: the date that the improvements were made; whether or not the grant was sufficient to cover the cost; who the grant was given by; and how the respondents found out about it. These were included in order to provide a possibility for collaboration with Andrew Wallace's (IESD) work on energy efficiency and fuel poverty.

As expected, none of the householders reported having RETs or micro-CHP installed, however these questions were retained during the revision, along with a request for permission to contact any householders who did for follow-up work.

Socio-demographic data

The collection of socio-demographic information is important for four key statistics that may explain differences in energy consumption that are not attributable to the building or appliance ownership and use: household composition, employment, income and education.

In the pilot study annual income was questioned directly using income brackets based on those used in the SUFC Core questionnaire, however the results show that seven of the respondents chose not to answer this question and one respondent added a comment questioning why this information was being sought (see table 3.13). This was taken as an indication that this question was deemed as too personal and an alternative approach using the Approximated Social Grade (ASG) classification system used by ONS was adopted for the final questionnaire. The employment of the highest wage-earner in a household was used to determine the classification. In hindsight this was a misjudgement as the results showed most respondents falling into the 'AB' category.

Table 3.13. Socio-demographic Information

Socio-demographic Information							
Total no. of people in home	**1**	**2**	**3**	**4**	**5**	**6**	**No response**
	5	19	5	11	0	1	1
No. of adults	**1**	**2**	**3**	**4**	**No response**		
	8	27	5	1	1		
No. of children	**0**	**1**	**2**	**3**	**4**	**No response**	
	26	5	9	0	1	1	
Income	**Under £5,000**	**£5,000-£9,999**	**£10,000-£14,999**	**£15,000-£19,999**	**£20,000-£24,999**	**£25,000-£29,999**	
	1	3	4	1	6	4	
	£30,000-£34,999	**£35,000-£39,999**	**£40,000-£49,999**	**£50,000-£74,999**	**£75,000-£99,999**	**>£100,000**	**No response**
	2	4	5	3	2	0	7
Full time employment	**0**	**1**	**2**	**3**	**Not applicable***	**No response**	
	5	18	9	2	1	7	
Part time employment	**0**	**1**	**2**	**Not applicable***	**No response**		
	21	12	1	1	7		
Education	**No formal education**	**GCSE or equivalent**	**NVQ / GNVQ or equivalent**	**A-level or equivalent**	**Degree**	**Higher degree**	**No response**
	2	10	2	8	10	6	5
*Respondent indicated they are a pensioner							

Additionally the section was extended to include a question on whether the respondents work from home, and if so whether or not this entails additional appliance use – specifically office equipment, catering equipment or machinery.

Aside from this significant revision two other minor alterations were made to this section in light of the results of the pilot work. The omission of a question asking for the number of retired persons in each household was corrected, as was the omission of professional qualifications (e.g. chartered accountancy) under the options for highest level of education.

Guidance notes

No evidence was found for or against the value of providing additional guidance notes with the questionnaire, and if so to whom such notes should be presented. Therefore in order to resolve this issue a tick box was added to the end of the questionnaire asking respondents whether or not the notes were used. 29 respondents reported not consulting the notes, with 11 reporting that they did, and 2 no responses. This was enough evidence to suggest that generally there was little need for supplying the information, however it was impossible to determine what impact they had on the answers given by the respondents who used them. Therefore a compromise was reached whereby more notes were included as part of the questionnaire and the guidance notes stripped down to essential information (definitions and the metric/imperial conversion table for thickness of loft insulation). This was facilitated in part by the more detailed numbering of questions in the revised format.

Table 3.14. - Use of Guidance Notes

Use of Guidance Notes		
Yes	No	No response
11	29	2

Format

The biggest difference between the pilot and revised questionnaires is the change in format. This was made for various reasons: to improve legibility; to enable a better numbering system to be used; and to draw out questions that the pilot results suggested had not been answered due to being overlooked.

The revised format was developed simultaneously with the online version of the questionnaire to ensure that the two resemble each other as closely as possible within the differing constraints of hard and digital copies.

3.8. Revision of the billing data permission slip

The process of establishing how to obtain electricity and gas consumption data proceeded concurrently with the roll-out of the pilot project. A meeting was arranged with E-on, a major utility company, at which point they appeared to be willing to release the data for those respondents who had completed the permission slip. Despite good intentions by management, the pressure of work on delegated staff meant that the data was never supplied and management seemed powerless or unwilling to intervene. The UK's largest gas supplier, Centrica, was completely unresponsive to repeated requests for data.

This period coincided with the roll-out of the SUFC Core Questionnaire and detailed site surveying of the Leicester study areas, so time and resources had to be diverted to meet these commitments. During this period contact was made with the DTI, who had collected consumption data for large numbers of UK households and were willing to release it if the permission slip was re-designed to incorporate the MPAN and MPRIN numbers used to identify individual electricity and gas meters. Furthermore, the DTI also agreed to approach the utility companies on our behalf for permission to release the data. This development was a major breakthrough as the data had not previously been made available to researchers and meant the difficulties of obtaining agreements from each utility supplier could be circumvented. As a result the permission slip was redesigned to meet the criteria set by the DTI. The option for respondents to provide copies of energy bills and contact details was retained as a back up option in the event of the provisional agreement falling through, however in the end this was not needed as the DTI delivered the data as requested.

3.9. Development of an online version of the questionnaire

The option of developing an online version of the questionnaire was revisited during this phase of the study; however despite several weeks spent on developing the online version only six responses were obtained this way. The real benefit of this work was to halve the time required to enter the data from the returned questionnaires from approximately 20 minutes to 10 minutes per questionnaire. A working paper discussing the research behind the development of the online version is given in Appendix 6.

3.10. Selection of study areas for the extended survey work

A variety of options were considered when selecting groups of dwellings to be targeted as part of the extended work. The response rate to the pilot project suggested that targeting between 1500 and 2000 dwellings in each selected area would be necessary to return a sufficient volume of data to be adequate for analysis. It was also necessary to consider how feasible it would be to use different numbers of study areas in terms of the time and resources required to produce and disseminate the questionnaires. In terms of cost versus expected response rate and in terms of using enough study areas for comparing the results from different types of built form the study areas selected for the extended work were those containing the largest groups of homogeneous dwellings that represented common built forms.

Another idea that had potential for reducing the resources and time involved was to restrict the work to the Leicester study areas, as this would have been easiest for conducting any on-site follow-up work that might have been required. However, this would have been too restrictive in terms of being able to target homogeneous groups of dwellings and would have required the re-use of Birstall, and potentially re-surveying of some of the dwellings targeted in the pilot project.

As discussed in section 3.6. Clarendon Park had been considered for use as part of the pilot project but then earmarked as having greater potential for use in the extended study work. As a result the 1674 dwellings in the area shown in Figure 3.2 were the first to be selected, and subsequently the first to be surveyed.

Having selected a group of terraces and a group of tenements it was decided that a group of detached or semi-detached properties would be most useful in terms of enabling the analysis of data between types of built form common in the UK. All four non-city centre areas of Sheffield and Edinburgh showed potential for fulfilling this objective and GIS was used to select groups within these areas to establish how many dwellings of each type existed in each case. This use of grouping showed that none of the four areas contained enough dwellings of either type to make up the 1500 to 2000 addresses deemed necessary for returning an adequate number of responses. Therefore the next best option of targeting both semis and detached properties in larger numbers was adopted, and 2083 dwellings in the Fulwood area of Sheffield were selected for this use based on the experiences of other researchers who had conducted surveys in the area and gained high numbers of responses. The dwellings selected are show in Figure 3.4, with semis shown in blue and detached properties shown in pink.

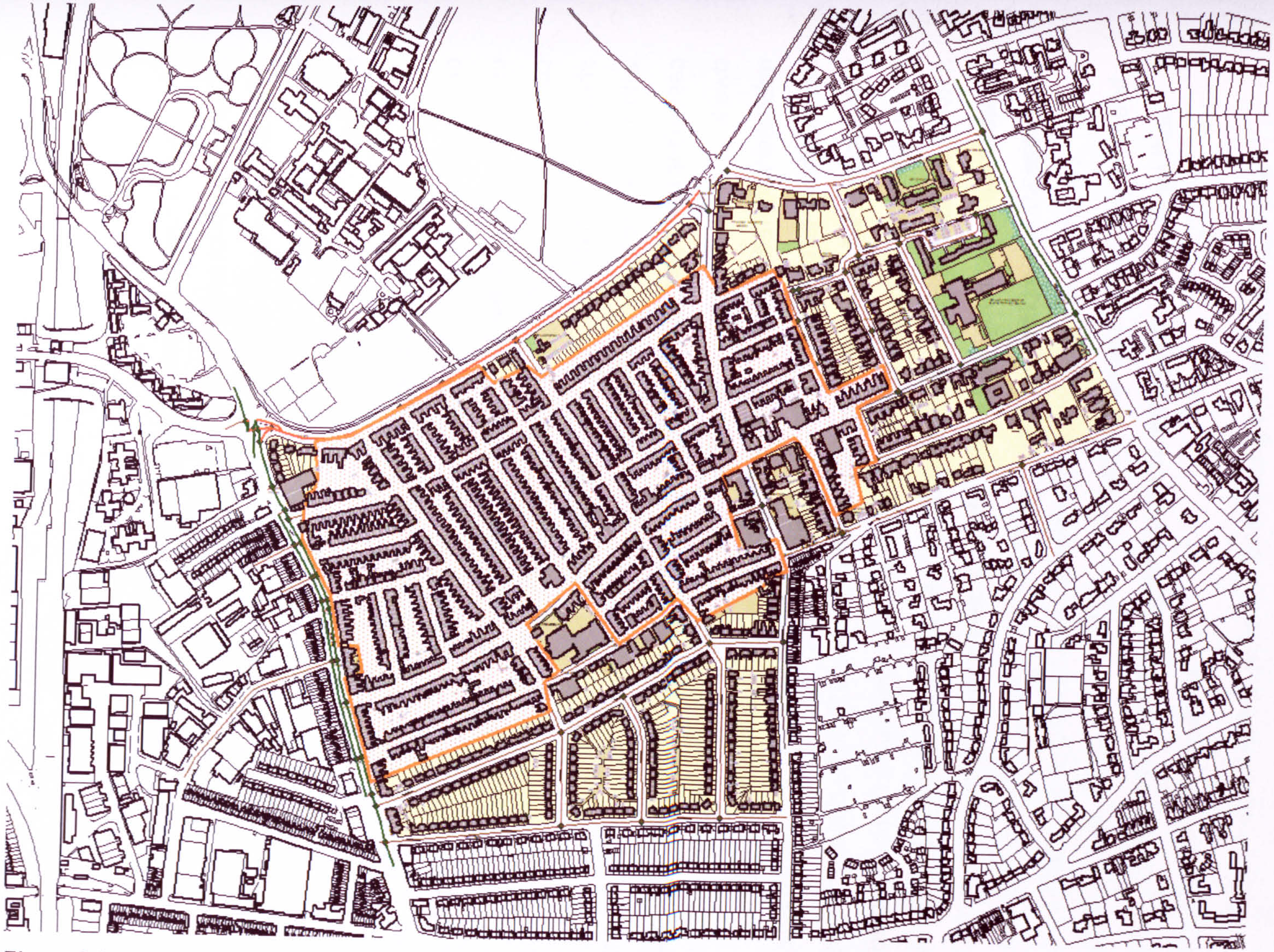


Figure 3.2. – Map of Clarendon Park, Leicester
City Form study area is in colour, the sub-area selected for the energy study is in red.

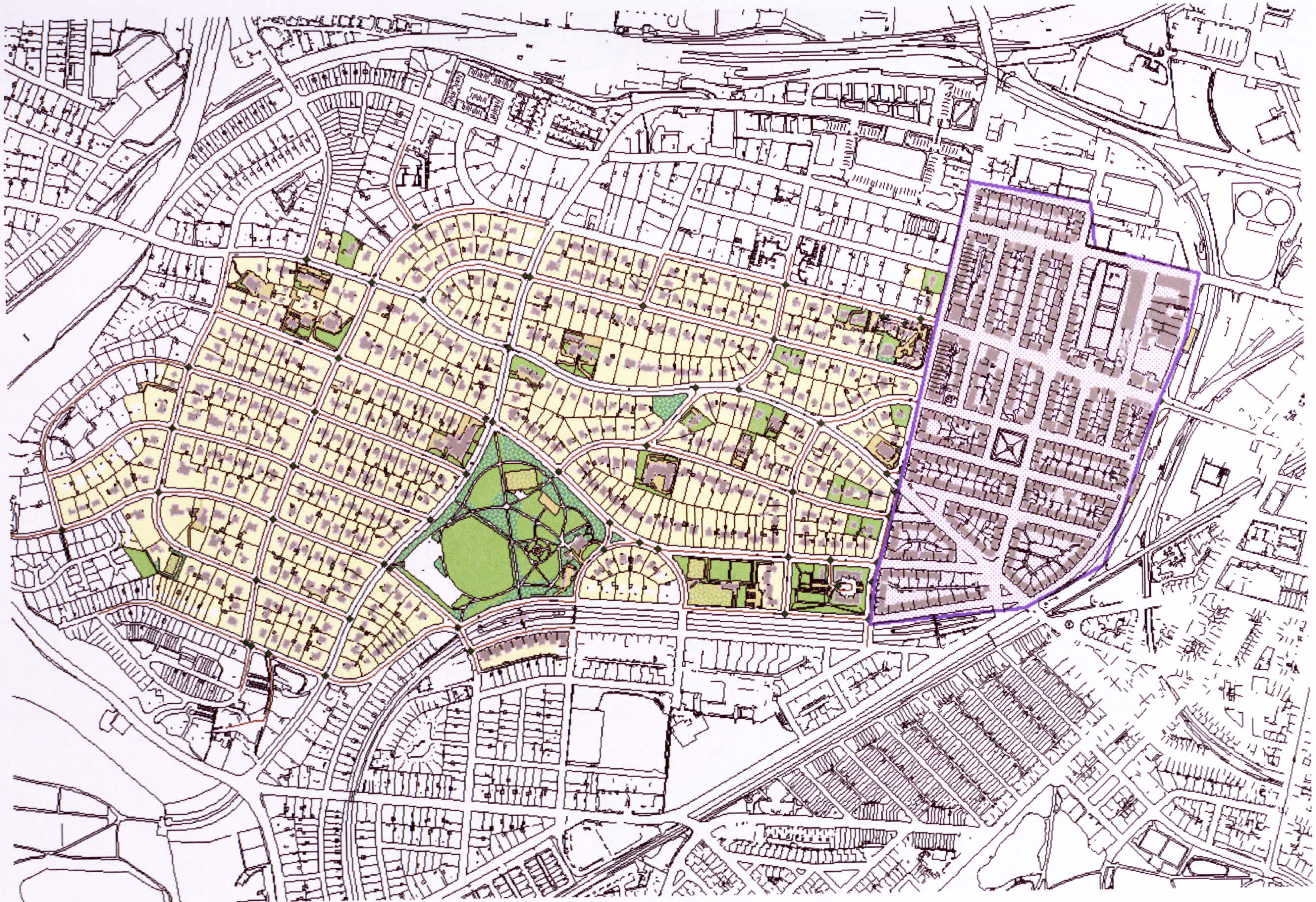


Figure 3.3. – Map of Pollockshields, Glasgow
City Form study area is in colour, the sub-area selected for the energy study is in mauve.

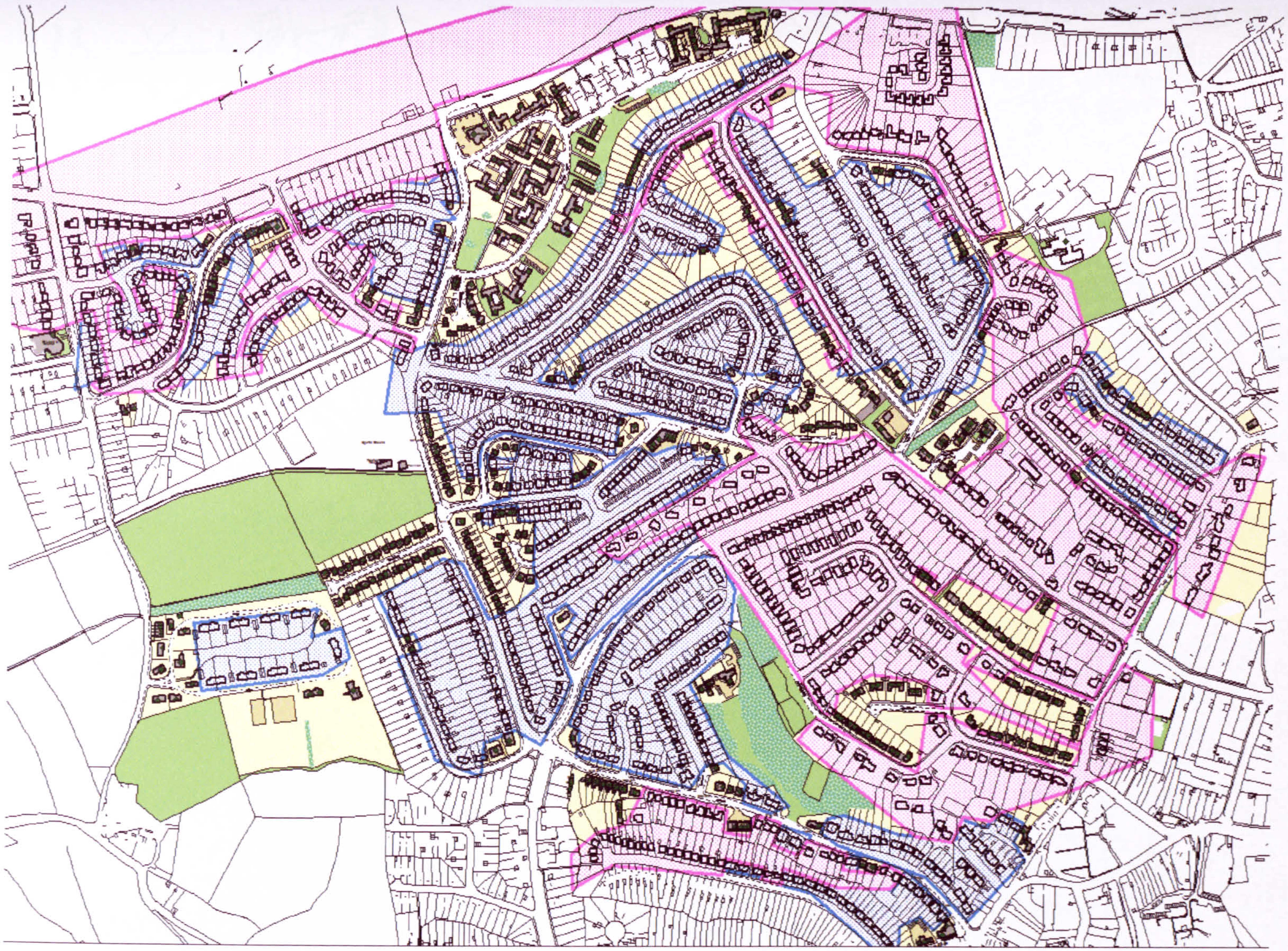


Figure 3.4. – Map of Fulwood, Sheffield
City Form study area is in colour, the dwellings selected for the energy study are in pink (detached dwellings) and blue (semis).

3.11. Chapter summary

This chapter has described the development of the survey instrument from the study of the data requirements of existing energy surveys and their appropriateness for inclusion in the questionnaire, through the drafting and roll-out of the pilot questionnaire to the production of the final questionnaire used for the study. The pilot project was invaluable in informing the development of the final version of the questionnaire, a copy of which is given in Appendix 5, along with the accompanying cover letter, mandate form and guidance notes.

The various options trialled for gaining access to individual annual energy consumption data have been discussed as this was critical to the success of the study. The breakthrough of gaining this data from the DTI was made only after the completion of the pilot project and to date this study represents the first release of this data to researchers in the UK.

The study areas containing the dwellings targeted for the work have been illustrated and the reasoning behind their selection discussed.

The online version of the questionnaire was of limited value in terms of the number of respondents selecting to use it therefore this has been mentioned only briefly. However, as this work raises a number of issues in respect to multi-modal sampling that may be of interest to other researchers a working paper on this exercise is given in Appendix 6.

Chapter 4. Descriptive Statistics and Secondary Data

4.1. Introduction

This chapter provides an overview of the basic statistics and results obtained for the three study areas. The results are compared with related secondary data at the closest level of granularity from publicly available sources. This analysis provides both an overview of key similarities and differences between households in the study areas and a context in which to interpret the more detailed analyses that follow. As the respondents were self-selecting, i.e. have the choice not to respond, it is necessary to take into account the degree to which they represent the average household in each area and note these differences in the subsequent analyses (the use of double sampling techniques to overcome the effects of self-selection was, on the grounds of cost, never an option).

The comparative data used here is drawn from two key sources. For the English cities the data was obtained from the Office of National Statistics Neighbourhood Statistics website, which following an update in August 2006 allows for the construction of study areas by building up output areas using an interactive map. The data required for these areas can then be selected, aggregated and downloaded as a single .csv file. This means that the aggregate data obtained for the two cities is a close geographical match to the study areas. In the case of Glasgow the data was obtained from the Scottish Census Results OnLine (SCROL) website. Owing to difficulties in obtaining data at the desired level of granularity from this source, the data quoted here is for the wider Pollockshields East Census Standard Ward, which is the second smallest area available.

For aspects of built form not covered by the 2001 Census the comparative figures are taken from the English House Condition Survey website and the Scottish House Condition Survey Key Findings 2003-2004 report published by the Scottish Executive. UK figures are taken from the 2001 report 'Living in Britain' by Walker et al.

All percentages are given to the nearest 0.5% unless quoted directly from either the EHCS or SHCS.

4.2. Response rates

Given the detailed nature of the questionnaire low response rates were expected from the outset and the number of questionnaires mailed out adjusted accordingly based on the response rate to the pilot project. Similarly it was expected that many respondents would complete the questionnaire but either not return the mandate form or return it without the MPAN and/or MPRIN numbers necessary for obtaining consumption data from the DTI. The number of responses does not include those returned incomplete and it was impossible to determine exactly how many were returned as a result of the reminder letters that were sent out 2-3 weeks after the initial mail out.

Two other factors that need to be born in mind with regard to the figures are the apparent failure of the Glasgow postal service to deliver some of the questionnaires and that in the case of Sheffield, the last study to be carried out, a cut-off date was imposed due to the necessity of gaining the consumption data from the DTI within the remaining available time. 16 questionnaires were returned after this date.

Table 4.1. Response rates for the three study areas

	No. questionnaires mailed	No. responses	Percent responses	No. completed mandates	Percent completed mandates
Leicester	1673	187	11.2	96	5.7
Glasgow	1729	116	6.7	46	2.7
Sheffield	2083	323	15.5	132	6.3

4.3. Dwelling type

The numbers of each type of dwelling captured within each study area are given in Table 4.2. The figures for Leicester and Glasgow demonstrate the success of the methodology in achieving the aim of targeting homogeneous built forms (terraces and tenements respectively); in the case of Glasgow it is likely that from local knowledge many, if not all, of the respondents who reported living in flats were actually in tenements. In the case of Sheffield a broader aim of capturing both detached and semi-detached properties was adopted, however the results are indicative of an error in the methodology that led to the targeting of one or more groups of flats. This was due to less local knowledge of the area and the elimination of only those dwellings where the addresses obtained from the GIS coverage clearly indicated a shared building.

Table 4.2. Dwelling type by study area

	Leicester	Glasgow	Sheffield
No data	0	0	3
Detached	1	0	118
Semi detached	4	0	160
Mid-terrace	58	2	4
Mid-terrace with passageway	95	0	1
End-terrace	15	0	1
End-terrace with passageway	11	0	0
Flat	3	34	35
Tenement	0	80	0
Maisonette	0	0	1
Total	187	116	323

The figures for Leicester show that 96% of respondents reported living in terraced houses, which are typical of the built form of the area and comprise 56% of the dwelling stock. The comparative figure for Glasgow is irrelevant due to the precision with which tenements could be selected and targeted using GIS.

For Sheffield, where the targeting was less focused on one specific dwelling type the results are much more closely representative of the area. 36.5% of respondents reported living in detached properties, compared to the census figure of 38%, for semis the figures were 49.5% and 44% respectively, and for flats and maisonettes 11% and 13.5%[2] respectively. Although achieving this close match was unintentional it shows that in this latter case the methodology was able to accurately reflect the mix of built form in the area, and as such should be useful in future studies.

4.4. Dwellings by Age and Tenure

The following tables show the results for dwelling age and tenure.

From table 4.3 it is apparent that there is a slight mismatch between the age categories used and the comparative figures are taken from the EHCS and SHCS, however it is still possible to draw some basic conclusions. As was expected for Leicester the vast majority of dwellings (91%) were constructed before 1950, with over half of those being pre-1900, compared to the EHCS figure of 38% of total stock being constructed pre-1945. This reflects Leicester's history of significant growth during the Industrial Revolution and further highlights the homogeneity of built form within the study area.

In contrast a mere 26% of the dwellings in the Sheffield study area were reported as being constructed pre-1950 and 32% post-1966, compared to the EHCS figure of 40% of total stock being constructed post-1965. The 42% that fall between these years may be indicative of the post-war housing boom.

As before, for Glasgow the targeting strategy masks the wider picture of dwelling ages in Pollockshields, and given that many respondents shared the same buildings there is likely to be some error in those reporting dwelling ages pre and post 1900. The SHCS report details 32% of Scottish homes as having been constructed before 1945, therefore giving further evidence to support the conclusion that the aim of targeting traditional Scottish tenements has been

[2] This ONS figure does not include purpose-built blocks of flats. This should be a better and more accurate comparison as dwellings with shared addresses were removed during the selection process.

achieved.

Table 4.3. Dwelling age by study area

	Leicester	Glasgow	Sheffield
No data	3	0	1
Pre 1900	98	78	0
1900-29	64	22	39
1930-49	8	2	46
1950-65	2	3	134
1966-76	0	1	85
1977-81	0	2	8
1982-89	1	0	5
1990-95	0	1	1
Post 1995	0	0	1
Don't know	11	7	3
Total	187	116	323

Owner-occupancy for the Leicester area is 61%, and 74% of respondents reported being homeowners. The ONS figure of 33% of dwellings in the area being privately rented on doubt reflects the proximity of Leicester University, with 23.5% of respondents being private renters. This compares to 10.2% of the total English housing stock.

Respondents in Sheffield were by far the largest group of owner-occupiers (91.5%) although this is only slightly above the ONS figure of 87% for the area. The most noticeable result was the number of dwellings owned outright – 64.5% as opposed to 45% for the area.

For Glasgow 82% of respondents reported being owner-occupiers compared to 58% for the census area.

Table 4.4. Dwelling tenure by study area

	Leicester	Glasgow	Sheffield
No data	2	3	2
Owner-occupied, owned outright	60	30	208
Owner-occupied, with mortgage	78	65	88
Rented from the Council	1	2	24
Rented from a Housing Association	1	3	0
Privately rented, fully-furnished	12	7	1
Privately rented, part or unfurnished	32	6	0
University managed accommodation	1	0	0
Total	187	116	323

4.5. Occupancy and Employment

As discussed in section 2.2.7 occupancy is a key factor in domestic energy consumption. The diversity of household compositions in the UK is reflected in the results from the study areas, and this section highlights the key findings from each study area. One difference in occupancy that may be lead to prominent differences in energy efficiency is that between single and multiple occupancy households. For Leicester single person households comprised 33% of responses, compared to 43% for the area, whereas for Sheffield the result was more representative of the area with 26.5% of respondents living alone compared to the census figure of 25%. In Glasgow the figure was 27.5%, compared to 34% for the Pollockshields census data. The proportion of single person households in the UK has grown from 23% in 1979 to 31% in 2001, with an almost equal fall in the proportion of households consisting of two adults and one or more children. According to a 2006 survey by the Campaign to Protect Rural England this figure is expected to reach 38% by 2026 (Aune, 2006).

Table 4.5. Dwelling occupancy by study area

	Leicester	Glasgow	Sheffield
No data	5	6	7
1 adult	62	32	86
2 adults	74	38	154
3 adults	11	8	21
4 or more adults	10	4	8
1 adult 1 child	5	0	1
1 adult 2 children	1	0	3
2 adults 1 child	7	5	17
2 adults 2 children	7	12	22
2 adults 3 children	1	4	0
2 adults 4 or more children	1	1	1
Other combinations of occupancy	3	6	3
Total	187	116	323

In all three cities the dominant occupancy group was two adults with no children, again reflecting the wider UK trend in changes in household composition. This group represented 39% of households in Leicester, 32% in Glasgow and 49% in Sheffield, with the census data giving figures of 33.5%, 17.5% and 40% respectively. The 2001 UK figure for these households was 35%, with only a 1% rise on the 1979 figure, therefore making respondents in Glasgow most representative of the UK, but least representative of their area.

In terms of density of occupation persons per bedroom (ppb) is a useful indicator. This was highest for Glasgow at 0.91 ppb, falling to 0.76 ppb for Leicester, with Sheffield dwellings being the least densely occupied at 0.63 ppb.

A notable employment statistic was the number of one or two person households with one or both occupants being retired. For Sheffield they made up over half (55%) of the total number of respondents, substantially more than the census figure of 38.5% for the area. These figures are a key differentiator between Sheffield and the other two cities, for which this figure was much more representative of the study areas. The proportion of respondents in Leicester falling into this category was 21% (19% for the area) and in Glasgow 9.5% (5%[3] for the area). The UK-wide figure for 2001 was 30%.

Table 4.6. Household composition by employment by study area

	Leicester	Glasgow	Sheffield
No data	12	5	8
1 retired	23	14	67
2 retired	10	8	97
1 full-time employed	35	24	24
2 full-time employed	37	28	33
1 or more, all in full-time education	15	0	1
All other combinations	55	37	93
Total	187	116	323

The full breakdown of all the combinations of household composition by employment is lengthy, however Table 4.6 shows the main groupings. Leicester and Glasgow had similar proportions of single occupants in full-time employment (19% and 21% respectively) and of two-person households with both in full-time employment (20% and 24% respectively).

Leicester had the highest percentages of households with one or more occupants all in full-time education (8%) and also the highest proportion of mixed-employment households with one or more occupants in full-time education (an additional 18%).

Very few households in any of the study areas contained only occupants in part-time employment and the percentages of households with one or more persons in part-time employment were similar (17%, 16% and 20% for Leicester, Glasgow and Sheffield) with the most common group being households with one person in full-time employment and one in part-time employment (6%, 5% and 10% respectively).

A factor in domestic energy consumption that is analysed in more detail in the chapters that follow is households where one or more occupants regularly

[3] This figure is only for households where all occupants are retired.

work from home. This figure was highest for the Glasgow respondents (28%) slightly lower for Leicester (25%) and lowest for Sheffield (14%). What is particularly interesting is that when retired persons (including the few that reported working from home) and the respondents who did not provide employment information are removed from the calculation approximately one third of all those households with at least one occupant in employment or education include a regular homeworker – 31%, 34% and 30% for Leicester, Glasgow and Sheffield respectively.

Table 4.7. Homeworkers by study area

	Leicester	Glasgow	Sheffield
Work from home	47	33	46
Don't work from home	140	83	277
Total	187	116	323

A final point of note is that Leicester and Sheffield contained notably greater diversities of household composition in terms of both adults and children and employment status.

One of the many pages of comment and analysis available on the ONS website contains the following interesting statistics:

"There are 21,660,475 households in England and Wales according to Census 2001, and 30.0 per cent of these (6.5 million) are one-person households - up from 26.3 per cent in 1991.

Nearly half of the one-person households (3.1 million) are one-pensioner only households and three-quarters of these (2,366,000) are occupied by a woman living on her own. However, in the remaining 3,376,000 one-person households, male occupants outnumber women by three to two.

Single-person households are least likely to have amenities such as central heating or sole use of a bath/shower and toilet. More than one-in-eight of single-person households do not have central heating - this amounts to over 383,000 pensioners and over 430,000 *non-pensioners."*

Source: http://www.statistics.gov.uk/cci/nugget.asp?id=350 [last cited 04/08/06]

The statistics for central heating and other amenities are addressed in section 4.7, however the results for occupants of single person households do bear out the point regarding pensioners. Leicester had the lowest proportion of single occupancy households containing retired people (37%) Glasgow was closest to the national average at 44%, whilst Sheffield had by far the largest proportion at 78%.

4.6. Education

As with the results of the pilot project the level of education of respondents provides perhaps the most significant difference from that typical of residents of the area. Note that, as the questionnaire requested the maximum level of education attained by any member of the household, whereas the census requests this on an individual basis, these figures are not directly comparable and the results from each area may be artificially high. However, the difference between the two figures in each case suggests that the respondents do live in households with higher than average levels of education.

The results for Leicester and Sheffield were remarkably similar. The number of households where one or more residents had achieved a level 4/5 qualification (degree, higher degree, HNC, HND or professional qualification) was 75% for Leicester and 74.5% for Sheffield, with the proportion of persons resident in both these areas achieving that level being 45%. The difference in Glasgow was much more significant, with 81% reporting a member of the household had achieved this level compared to 25.5% of the population of the area. However the strongest suggestion that these respondents were more qualified than average comes from the proportion of households where one or more residents had gained a higher degree – 35%, 34.5% and 28% for Leicester, Glasgow and Sheffield respectively.

Table 4.8. Maximum level of education achieved by a member of the household by study area

	Leicester	Glasgow	Sheffield
No data	11	10	16
No formal education	7	1	24
GCSE or equivalent	16	3	21
NVQ / GNVQ or equivalent	1	1	6
HNC / HND or equivalent	4	13	20
A-level or equivalent	12	7	15
Professional qualification	15	6	52
Degree	55	35	78
Higher degree	66	40	91
Total	187	116	323

4.7. Comparison of Dwellings in Study Areas with UK Dwelling Stock

The DTI (2006a) has a wide range of energy statistics and indicators for the UK's dwelling stock available online. This section compares dwelling details from the three study areas with this data in order to assess how representative they are of the average UK dwelling.

4.7.1. Insulation and Glazing

Three commonly used indicators of dwelling energy efficiency are the presence of cavity wall insulation and double glazing and the thickness of loft insulation.

For 2004 36.82% of UK homes had been fitted with cavity wall insulation, however the situation was noticeably different within the study areas: 8.5% of respondents in Leicester reported brick walls with either filled or unfilled cavity insulation, although a significant number (33%) answered 'don't know'. As shown by the largest group (57%) the typical dwelling stock for the area consists of the brick terraces found throughout the wider city, which because of their age would not be expected to have cavity walls. A similar picture emerged for Glasgow with a mere 3.5% of respondents reporting cavity walls, and again this can be put down to the type and age of the dwellings, which are almost all traditional brick/stone tenement blocks. The number of 'don't knows' was 33.5%. For Sheffield, with its newer and more diverse group of dwellings the statistic was significantly different, with 85% of respondents reporting cavity wall insulation. Also, the type of wall construction was far more diverse, although brick walls were predominant respondents also reported stone, timber frame, breeze blocks, and one noted 'pre-fabricated'. Sheffield also returned the lowest proportion of 'don't knows' at 10%.

Table 4.9. Walls and insulation by study area

	Leicester	Glasgow	Sheffield
No data	0	0	1
Brick + No data / Don't know	63	11	32
Brick + Solid	107	10	9
Brick + Cavity	14	1	143
Brick + Filled cavity	2	1	117
Stone + No data / Don't know	0	28	0
Stone + Solid	0	55	4
Stone + Cavity	0	7	4
Stone + Filled cavity	0	1	3
Other combinations	1	2	10
Total	187	116	323

Penetration of double glazing was also highest in Sheffield (95.5%) of which most (84%) was uPVC. For Leicester this figure fell to 44%, with the predominant form of glazing being single with wooden frames. Glasgow had the lowest proportion of double glazing at 25%. The UK figure for 2004 was 42.82%[4].

[4] The DTI uses the definition '80% or more' to classify a dwelling as having double glazing, the definition used in the energy questionnaire was 'most or all' therefore the results can be deemed as directly comparable.

Table 4.10. Windows and glazing by study area

	Leicester	Glasgow	Sheffield
No data	0	1	3
Single + Wood	100	79	4
Single + Metal	1	3	2
Double + Wood	14	11	38
Double + Metal	2	2	11
Double + uPVC	67	16	260
Other combinations	3	4	5
Total	187	116	323

A similar picture was observed for loft insulation, although this was one of the most poorly answered questions. 22.5% of Leicester respondents reported loft insulation of 4 inches or thicker, but the majority (51%) answered 'don't know'. 42% of respondents in Sheffield indicated 4 inches or more, and although the proportion of 'don't knows' was the lowest of the three cities it was still relatively high at 28%. Understandably most respondents in Glasgow indicated 'none', 'don't know' or wrote in 'not applicable'. The low level of completeness of this question means that this will have to be taken account of in later analyses. The DTI figure for 2004 is 56.9%.

4.7.2. Conservatories

Following the failure of the pilot project to return any significant numbers of dwellings with conservatories the number of questions used in the extended work was scaled back, however it was still necessary to identify dwellings with conservatories due to their potential impact on energy efficiency. Initially conservatories were thought to decrease energy consumption by around 10% by acting as a buffer zone. However, an update of a study carried out in 1993 showed that the trend towards households heating conservatories for all round use was continuing to increase, the number now installing cooling systems is growing and the result has been a net increase in energy consumption for dwellings with conservatories (POST, 2005).

Unsurprisingly only one respondent in Glasgow reported owning a conservatory. Only 12 were reported in Leicester, of which 4 respondents failed to complete the section and of the remaining 8 half reported a double glazed structure heated as a living area. However, Sheffield produced results that support the wider assertions. Of the 70 respondents reporting conservatories only 4 failed to fully complete the question and of the remaining 66 36% reported as heating them as a living area, with a further 30% reporting that they heated them to protect plants. Although no strict definition of 'to protect plants' was given with the question it does indicate that heating is in use to maintain a minimal level of thermal comfort.

4.7.3. Space Heating

Although the proportion of energy used for domestic space heating has remained relatively constant over the last 30 years the type and efficiency of the systems in use has changed noticeably, and the results from the three study areas serve to demonstrate this diversification.

For both Leicester and Glasgow 89% of respondents reported having gas-fuelled radiator systems for their main heating. One key difference here was the type of system in use, with 68% of these in Glasgow reporting owning combi boiler systems, compared to 46.5% in Leicester. Of the Leicester group 4% reported owning condensing systems, with a further 4% owning dual combi-condensing systems, whereas in Glasgow there was only one report of each type. Another notable difference was the proportion of these systems that were fitted with thermostatic radiator valves, in Leicester only 56.5% of systems were so equipped, similar to the figure of 52.5% recorded for Sheffield, whereas for Glasgow 79% of systems were fitted with TRVs. The second most common form of main heating in Leicester was storage heaters (4%) and gas fires in Glasgow (7%).

Although the proportion of respondents in Sheffield reporting using gas fuelled radiator systems as their main form of heating was almost the same as for the other two cities (87.5%) this masks the number of dwellings equipped with the second most common form of main heating, gas fuelled ducted air systems (10%). Of those with radiator systems normal/conventional systems made up more than half (55.5%) with combi systems comprising just 26.5% of the total, however Sheffield did produce the highest proportion of condensing systems (10.5%) again making Sheffield the most diverse of the three study areas.

Table 4.11. Main heating systems by study area

	Leicester	Glasgow	Sheffield
No data	12	4	7
Radiator systems	167	104	283
Storage heaters	8	0	0
Gas fires	0	8	0
Gas ducted warm air systems	0	0	33
Total	187	116	323

The DTI gives the figure for households with central heating systems in 2004 as 91.55%, of which 76.73% are gas fuelled systems, however this categorisation fails to delineate between the types of gas fuelled systems in use so it is not possible to validate how closely this greater diversity amongst the newer dwelling stock in Sheffield mirrors the wider UK trend.

4.7.4. Heating system controls

Having greater control over a dwelling's heating regime should, in theory at least, reduce the amount of energy consumed by space and water heating, however this impact will be tempered by how effectively occupants make use of the available controls. Without a detailed and intrusive longitudinal survey it is impossible to quantify the impact of the level of control on reducing domestic energy consumption, however distinguishing between the type of controls in use does at least provide an indicator of how frequently occupants may change their heating levels.

Also, the extent of a dwelling's main heating was questioned but produced no results of significance at this stage of the analysis, with almost all respondents in all three cities reporting that their main heating served most or all of their rooms.

Table 4.12. Heating system controls by study area

	Leicester	Glasgow	Sheffield
TRVs			
No data / Not applicable	31	19	43
Present	94	82	149
Not present	62	15	131
Total	187	116	323
Heating system controls			
No data / Not applicable	4	5	6
No control / manual	31	24	15
Mechanical clock/timer	77	59	164
Digital	75	28	138
Total	187	116	323
Thermostats			
No data / Not applicable	0	0	1
Present	75	27	262
Not present	112	89	60
Total	187	116	323

Mechanical clock/timers were the most common controls reported by respondents (51% of all respondents in Glasgow and Sheffield, 41% in Leicester). The group with the least control over their heating regimes was Glasgow, with 20.5% reporting manual/no controls, those with the most control were the households in Sheffield with only 4.5% ticking this box. The highest number of households with digital controls was found in Sheffield (42.5%) a figure which was not raised by the group of dwellings with gas fuelled ducted air systems, of which only 7 out of 33 were equipped with digital controls.

The question on thermostats and settings was much more revealing. Sheffield emerged as the only one of the three cities where the majority of respondents reported having thermostats, and also having the lowest average setting. Here the issue of the 33 households with gas fuelled ducted air systems was a factor as all reported thermostats, although not all reported temperature settings. Some respondents also wrote in comments that their thermostats and/or digital controls did not display the actual temperature but merely a scale. As might be expected Glasgow returned the highest average setting, even with the removal of an unlikely outlier (although the average is by far the least precise due to being based on only 19 records). The following table gives the ranges and averages for the results from each city (note: temperatures reported in °F were converted to °C and where a range of temperatures was given an average was taken in each case).

Table 4.13. Thermostats and settings by study area

Thermostat setting	Leicester	Glasgow	Sheffield
Total no	75	27	262
Max (°C)	30	28	27
Min (°C)	15	15	6**
Range (°C)	15	13	21
Average (°C)	19.8	20.4	17.2
No setting given	13	8*	27
*Includes 1 respondent reporting 45°C removed as an outlier			
**Although this result was unexpectedly low it was from one of 5 households reporting settings below 15°C			

4.7.5. Secondary heating and use of portable electric heaters

How the use of secondary heating effects a household's energy consumption is a complex issue, as is shown by the range of types in use, where they are used, and the number of respondents reporting using one or more portable electric heaters. As such the impact of secondary heating is difficult to quantify where detailed behavioural data is unavailable. A standard assumption is that secondary heating is used to boost the temperature of the main living areas, however the changing trends in household composition suggest the amount of time householders spend in different rooms may be changing and the role of secondary heating may be increasing as a factor in overall energy consumption. For example, for single person households it may be more efficient to reduce the level of main heating and use secondary heating to improve the comfort level in individual rooms, which may or may not be the traditional main living space. This may also be true for households where one or more residents work from home and for multiple occupancy dwellings.

An interesting statistic with regard to secondary heating is that approximately one third of all respondents in all three groups reported having no secondary heating and the range of the proportion of the most common form of secondary heating, gas fires, across all three groups was a mere 5% (39.5% in Leicester, 44.5% in Sheffield). Furthermore, whilst the results for all three groups showed that the most common area where secondary heating was in use was the living/dining areas, the use of secondary heating in bedrooms, kitchens and bathrooms was also apparent (Table 4.14).

Table 4.14. Use of secondary heating by study area

Secondary heating	Living / dining rooms	Bedroom(s)	Kitchen	Bathroom(s)	Other area(s)
Leicester (out of 126)	98	42	46	26	25
Glasgow (out of 77)	52	30	20	20	8
Sheffield (out of 206)	161	62	48	50	32

The question regarding the use of portable electric heaters also provided some interesting results. Whilst the proportions of respondents reporting the use of one or more portable heaters in Glasgow and Sheffield were 20% and 24% respectively, the figure for Leicester was 33.5%. Leicester also stood out for another statistic - the ratio of the number of areas respondents reported using secondary heating to the total number of respondents reporting the use of secondary heating was the highest of the three groups (1.88:1). These results may be indicative of lower levels of thermal comfort being provided by the main heating systems in the Leicester dwellings and/or a reflection of the greater diversity of household composition in the Leicester sample leading to a greater diversity in the use of secondary heating.

4.7.6. Water heating

This group of results provided few surprises. Using a boiler/main heating system combination was by far the most common option for water heating, as was expected given the predominance of boiler/radiator systems. The statistics were 72.5%, 76.5% and 73.5% for Leicester, Glasgow and Sheffield respectively. Respondents in all three cities also reported using single/dual immersion and gas single/multi-point systems, whilst several respondents in Leicester were most likely to use another option in addition to a boiler system. Sheffield respondents were again the most diverse in their choices of water heating, with 7 reporting the use of gas circulator systems fitted directly to their hot water tank or cylinder (an option not given in the questionnaire).

Whilst the number of results for cylinder size and insulation was significantly reduced due to the prevalence of combi boilers in Leicester and Glasgow the results for boiler age and service history were encouraging from an energy efficiency point of view. In each city the largest group of respondents was those reporting a boiler age of less than ten years and serviced within the last year (30% in Leicester, 33.5% in Glasgow and 39% in Sheffield). However, the difference between Sheffield respondents and those in the other two cities becomes more noticeable when considered in terms of boiler service history only, with 69% of Sheffield respondents reporting their boiler being serviced within the last year as opposed to 53.5% and 50% in Leicester and Glasgow respectively (interestingly the same difference is evident if the number of respondents not knowing their boiler age is removed from the calculation).

4.8. Appliances

The questionnaire was designed to include questions that are more detailed than those used for the surveys carried out by the DTI, particularly with respect to appliance ownership and use. However, at this level of analysis it is possible to draw some summary conclusions as to how closely respondents in the three study areas represent the wider UK population. This section gives a breakdown of the basic results by appliance category.

4.8.1. Cold appliances

Cold appliances are a useful place to start when attempting to quantify the impact of appliance use on domestic energy consumption as they are high energy users that are almost always left switched on (one respondent on a low income did comment that they switched theirs off to help save money on fuel bills). However, cold appliances come in a variety of forms and, as shown by the results, many households are now using them in combinations that would have been unusual 30 years ago.

In the more densely populated study areas in Leicester and Glasgow the most common choice of cold appliance(s) remains the conventional fridge-freezer (36% and 33% in each case) however the second most common choice, and the most common choice for Sheffield respondents, was a freezer combined with one other cold appliance. In Sheffield this option accounted for 42% of responses, but even in Leicester and Glasgow 32% and 31% of respondents owned a freezer plus an additional cold appliance. Owning one non-fridge-freezer cold appliance (usually a fridge with a freezer compartment) was most common amongst Leicester respondents (20%) falling to 10% in Glasgow and 9% in Sheffield.

One key difference that again set Sheffield respondents apart from those in the other two cities, and that may be indicative of a wider trend in technology choice, is the number of respondents reporting owning more than two cold appliances. For the purposes of this analysis this category was split into those with more than two cold appliances who owned a separate freezer and those that did not, and this served to help identify a difference between Leicester and Glasgow. Ownership of more than two cold appliances including a freezer was 3% for both cities, but in Glasgow 15% of respondents reported owning more than two excluding a freezer (for Leicester this was a mere 1%). This figure was lower for Sheffield (11%) but the big difference was that 14% of Sheffield respondents reported owning a freezer plus at least two other cold appliances.

Table 4.15. Ownership of cold appliances by study area

	Leicester	Glasgow	Sheffield
Single appliance - Not a fridge-freezer	37	12	30
Fridge-freezer only	68	39	67
2 appliances - including a separate freezer	59	36	135
More than 2 appliances - including a separate freezer	6	3	44
2 or more appliances - no separate freezer	2	17	37
No / insufficient data	15	9	10
Total	187	116	323

The DTI has data on the ownership of cold appliances for 2004 but this is split into just four categories (fridges, fridge-freezers, and chest and upright freezers) and does not capture combinations. For fridge-freezers all three study areas returned results below the UK statistic of 64.92%, and the range is small, with Sheffield at 40% and Glasgow at 44%, unsurprising given the tighter spatial constraints of living in a flat. Total freezer ownership is given as 45.01%, and yet again Sheffield comes out above the national figure with 56% of respondents reporting owning a freezer and Leicester and Glasgow falling below the figure at 35% and 34% respectively.

4.8.2. Wet Appliances

Wet appliances constitute the second major element in the amount of domestic energy consumption attributable to appliance ownership and use. Although not essentially 'always-on' devices they are high energy consumers when in use, and as the frequency of use in theory relates to occupancy it should be easier to quantify their impact on energy consumption than for other common but lower-energy using appliances.

The DTI has data on the ownership of washing machines, tumble dryers, washer-dryers and dishwashers, but again lacking the details of multiple ownership obtained by the questionnaire. 2004 figures for the UK were 79.64%, 36.11%, 14.92% and 29.2% respectively for the four appliances.

Washing machine ownership was higher than the national figure amongst all three groups (82% in Leicester, 88% in Glasgow and 85% in Sheffield) whereas tumble dryer ownership followed the pattern of Leicester and Glasgow returning results below the UK statistic (17.5% and 23.5%) and Sheffield above at 42%. With Sheffield dwellings having larger floor areas than those in the other two cities this suggests that it may be feasible to make some assessment of ownership of major appliances, and thereby the energy consumption attributable to them, based on floor area.

In the case of washer-dryers the results agreed with the prior assumption that the Glasgow ownership would be more space conscious and therefore that ownership would be highest for this group (23.5%) with Leicester (12.5%) and Sheffield (14.5%) being close to the national figure. The Sheffield result was higher than expected, but this may be explained by the unintentional capturing of some flats. In terms of combinations (or lack of) of wet appliances the most common results for all three cities were washing machine only, followed by washing machine and tumble dryer.

Table 4.16. Ownership of wet appliances by study area

	Leicester	Glasgow	Sheffield
No / insufficient data	11	5	10
Washing machine only	120	74	140
Washing machine and Tumble dryer	33	25	126
Washer-dryer	22	7	38
Washer-dryer and Tumble dryer	0	0	1
Washing machine and Washer dryer	1	3	1
Other combinations	0	2	7
Total	187	116	323

For dishwasher ownership Leicester respondents were the only group falling below the UK statistic (20%) with Glasgow returning 37% and Sheffield 49%.

4.8.3. Cookers

This was the last section relating to appliances where the generalisations between Sheffield and the other two cities appeared to be holding true. However, due to the lack of freely-available reports for comparison it is not possible to assess how closely the results match the UK figures for ownership*.

For both Glasgow and Leicester 51% of respondents reported owning a gas cooker, with almost all of the remainder split between electric cookers and gas hobs with electric ovens. Unusually, given the prior expectation that occupants of flats would be less likely to have a gas supply, ownership of electric cookers was higher in Leicester – 21% compared to 15%. For Sheffield the split was almost equal (33% gas, 30% electric, 31% gas and electric) and Sheffield respondents were the only group who reported any ownership of Agas, although this comprised only 1% of responses.

Table 4.17. Cooker type by study area

	Leicester	Glasgow	Sheffield
No data	4	3	5
Gas	97	60	109
Electric	39	16	96
Gas hob & Electric oven	44	36	102
Gas hob only	1	0	0
Gas kitchen range	1	0	2
Gas hob & Electric & Gas oven	0	0	3
Aga	0	0	3
No cooker	1	1	3
Total	187	116	323

Results for microwaves were sub-divided by their power, although differentiating on this basis produced no results worth reporting due to the degree of disaggregation. Ownership was highest in Sheffield at 86% (8% reported not

* A market research report is available but at considerable cost. At the time of writing the DTI only had figures for power consumption attributable to usage.

owning a microwave, 6% failed to answer the question) and again the figures for Leicester and Glasgow were very similar, at 76% and 75% respectively (of the remainder 12% and 9% did not complete the question).

4.10. Lighting

A different approach was taken in an attempt to quantify the impact of lighting on domestic energy bills, in part because respondents were thought unlikely to detail the number location and power consumption of individual lights, and also to attempt to relate the results to the correlation observed between the use of energy efficient light bulbs and wider domestic energy efficiency by Palmer & Boardman (1998). As such respondents were only asked to specify the number in use and their locations.

When the results for each study area are expressed as percentages there is an apparent pattern in the number of energy efficient light bulbs used by households in the three cities (Figure 4.1).

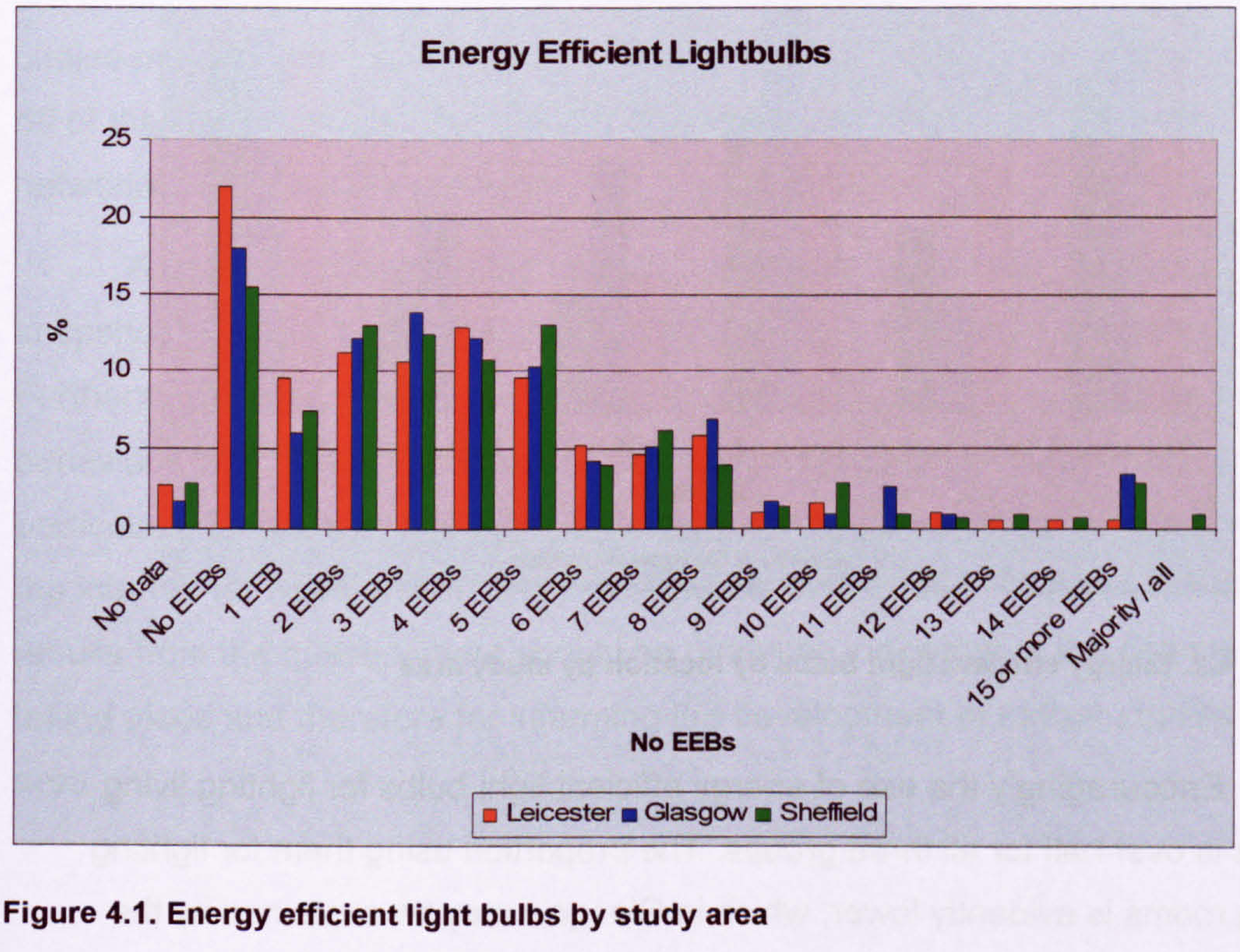


Figure 4.1. Energy efficient light bulbs by study area

The number of households reporting not using any energy efficient light bulbs is the largest group across all three cities, however those using two to five comprises over 40% of the respondents in all three areas, after which the group using between six and eight comprises over 10% of the remainder, followed by a tail-off leading to some unusually high and quite possibly erroneous results. However, their use should be expected to make a noticeable contribution to energy efficiency only where they used in the most frequently occupied rooms in a dwelling. For this reason respondents were asked to indicate the key areas where energy efficient light bulbs were in use, the results of which are shown in Figure 4.2 (percentages shown are based on the number of respondents who reported using energy efficient light bulbs, not the total number of responses).

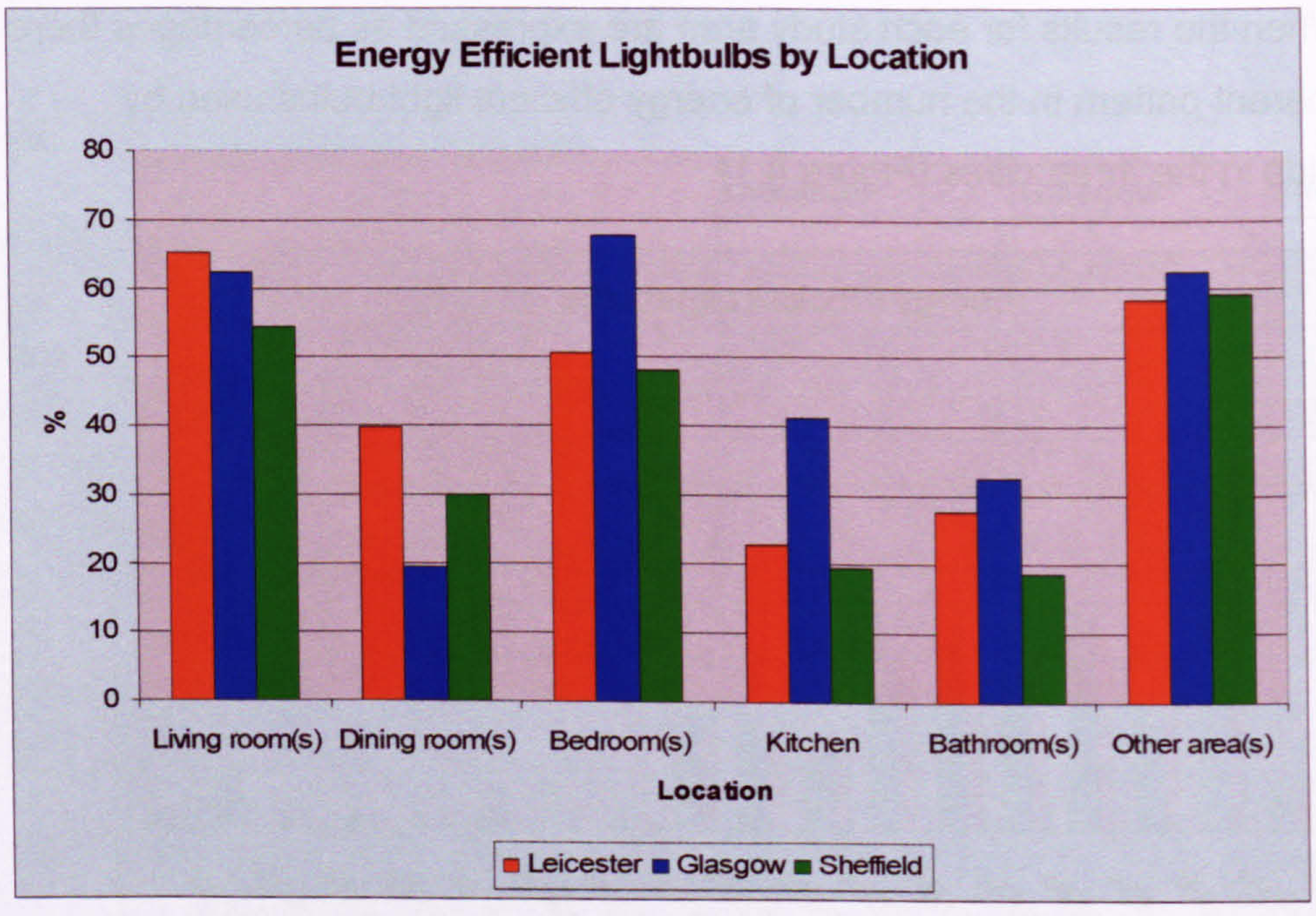


Figure 4.2. Energy efficient light bulbs by location by study area

Encouragingly the use of energy efficient light bulbs for lighting living rooms is over half for all three groups. The proportion using them for lighting dining rooms is evidently lower, which in Glasgow may be explained by the absence of separate living and dining rooms in tenement flats (although this cannot be confirmed) but it seems unusual to observe a similar decrease in the other two cities. Finally, Glasgow comes out highest for the four other specified locations, with the only noticeable difference between Leicester and Sheffield respondents being the proportions reporting their use in bathrooms.

4.11. TVs, Computers, Digiboxes and Broadband

By 2004 99% of all UK households owned a TV, and 55% of households could receive digital, cable or satellite feeds. In the same year ownership of a home computer reached 60% of all households, with 51% having internet access from home (Sattar, 2005). Having reached the stage where the majority of UK households have a fixed line telephone connection, a TV equipped to receive a digital signal and a computer connected to the internet (either by dial-up or broadband) future studies of the domestic energy consumption attributable to the use of high-tech goods will need to take into account *how many* of each device are owned, not just ownership per se. As is discussed in section 2.2.6 technology choice may become an increasing factor, especially in the run up to the switching off of the UK's analogue transmitters and as the use of 'always-on' home networks become more prevalent.

A limitation regarding the use of these results is that they are simply a snapshot of technology ownership at a time of rapid technological change. Furthermore, more research is needed into how these changes are affecting user behaviour (and hence the amount of time spent using different devices) particularly as younger households increasingly turn away from TV and towards the internet for news and entertainment (Martinson, 2006). However, the initial results from the questionnaire should be useful as indicators of the changes taking place and therefore for informing the development of further studies in this area.

TV ownership and use[5] was above 90% for all three groups of respondents – lowest in Leicester (91%, although the remaining 9% includes the 5% who did not provide information) and highest in Sheffield (96%) however, the number of TVs owned ranged from 0 to 5 in Leicester and Sheffield and 0 to 8 in Glasgow. The proportions of those who reported owning just one TV varied by only 4% (51% in Sheffield to 55% in Glasgow) but more interesting differences were observed in the proportions reporting owning 2, 3 or 4 TVs. Ownership of two TVs was 27%, 34% and 35% in Leicester, Glasgow and Sheffield respectively, and whilst ownership of three was only 1% in Glasgow it reached 5% in Leicester and 7% in Sheffield. Between 2% and 3% of respondents in each city reported owning four. In short, the ownership of more than 2 TVs was 5% in Glasgow and 10% in Leicester and Sheffield. The simple conclusion here is that, based on the other results outlined thus far, the data for Sheffield is indicative of more affluent and technology-aware households with more space for home entertainment systems, yet the inconsistencies in the evidence from the other two cities suggests the reality is more complex.

Table 4.18. TV ownership by study area

	Leicester	Glasgow	Sheffield
No data	9	4	10
0 TVs	7	3	2
1 TV	103	63	167
2 TVs	52	40	114
3 TVs	9	1	23
4 TVs	3	4	5
5 TVs	2	1	2
7 TVs	1	0	0
8 TVs	1	0	0
Total	187	116	323

[5] The wording of these questions specified not just ownership, but also that the TVs or computers were in regular use. This was intended to remove any inaccuracies related to the reporting of stock-piled out-dated or non-functional devices.

Added to this is the evidence from the question asking for the number of digiboxes in use by respondents. Although the accuracy of the figures suffers from the number of respondents not completing this question (16% to 18%) the results suggest that the digital switchover is well under way in all three study areas, with Leicester coming out on top. Only 22% of Leicester respondents reported not owning a digibox (30% in Glasgow and 33% in Sheffield) 54% reported owning one and a further 6% reported owning two. The second highest group was the Glasgow respondents (49% owning one, 3% owning two and 2% owning three) with only 50% of Sheffield respondents having made the switch (5% owning two and 1% owning three). This represents an interesting, although not significant, reversal in the general trend observed thus far.

Table 4.19. Digibox ownership by study area

	Leicester	Glasgow	Sheffield
No data	33	18	55
No digibox	42	35	105
1 digibox	100	57	146
2 digiboxes	12	4	15
3 digiboxes	0	2	2
Total	187	116	323

Further complexity is suggested by the results for the number of computers in use in each household. Here Glasgow respondents reported the highest levels of ownership, with 54% of households owning one and a further 11% owning more than one. Sheffield falls slightly behind with 52% owning one and a further 10% owning more than one, but for Leicester only 43% of households owned one computer and 10% owned more than one. Both Glasgow and Sheffield respondents reported owning up to five computers, whilst for Leicester the maximum figure was three, making Leicester the only area returning a result lower than the national figure.

Table 4.20. PC ownership by study area

	Leicester	Glasgow	Sheffield
No data	38	20	39
0 PCs	50	21	84
1 PC	80	63	171
2 PCs	17	8	21
3 PCs	2	2	5
4 PCs	0	1	1
5 PCs	0	1	2
Total	187	116	323

Further uncertainties are raised by the final question on ownership and use of high-tech appliances, that of broadband access. Given that the vast majority of UK households have a phone line, and that accessing a dial-up connection does not require an additional power-consuming device, the question of dial-up access was removed after the pilot project on the basis that it can be assumed that any household with a computer is at least capable of accessing the internet. The more valuable information comes from those with broadband access, due to the assertion that households with broadband access are more likely to leave their computers on and connected when not in use (hence the distinction made between always-connected and not always-connected broadband services) and also that households with broadband access may be using additional always-on devices (be they cable or satellite boxes that also provide TV or separate routers – for example wireless networking boxes).

Here significant differences emerged between the respondents in the three cities. Sheffield was the only area where less than half of respondents reported broadband access (43% in total, 33% always-connected). 53% of Leicester respondents reported broadband access, but only 23% were always connected, whereas for Glasgow 50% had always-connected broadband access and a further 7% had a dial-in connection. In hindsight, given the higher density living in the Glasgow tenements, it would have been interesting to know if, and how many, households shared a network (e.g. by using wireless technology).

Table 4.21. Broadband access by study area

	Leicester	Glasgow	Sheffield
No broadband / No data	87	50	183
Not always connected	57	8	33
Always connected	43	58	107
Total	187	116	323

What seems clear is that, whilst there appears to be a relationship between socio-demographics and dwelling floor area to the number and type of cold and wet appliances owned by each household, that generalisation does not apply to ownership and use of high-tech consumer goods.

4.12. Summary statistics for the energy consumption data

In order to analyse differences in domestic energy consumption within groups of homogeneous built forms the Sheffield sample was split into detached and semi-detached dwellings. This also resulted in datasets of comparable size (52 terraces, 48 detached and 52 semis). A problem arose with using the data for the Glasgow tenements when aerial photographs released after the completion of the survey revealed the targeted tenement blocks to be of a form containing a large circulation space within the building envelope. This made it impossible to accurately determine the floor areas of the 37 flats for which consumption data was obtained. Several attempts were made to produce an estimated figure for floor area using measurements for nearby tenements from descriptions published on the websites of estate agents, however this failed to produce a justifiable estimate. As floor area was an important variable for use in the later analyses of energy consumption these had to be restricted to the Leicester and Sheffield samples.

For 2004 the percentages of the records of annual electricity and gas consumption data for dwellings in Great Britain collected by the DTI that were based on two actual meter readings were 88.8% and 90% respectively. Where it was not possible to obtain two meter readings the figures were based on estimates, although it was not possible to ascertain which was which (DTI, 2005). Descriptive statistics for the electricity and gas consumption data obtained for the Leicester terraces and the detached and semi-detached Sheffield dwellings are given in Table 4.22.

Table 4.22. Descriptive statistics for annual energy consumption (in kWh) for the three study areas

Study Area	Leicester		Sheffield Detached		Sheffield Semis	
Descriptive Statistics	Electricity	Gas	Electricity	Gas	Electricity	Gas
Mean	3567	23579	5229	33809	4053	24107
Standard Error	359	2416	406	1799	284	1372
Median	3031	19504	4253	31004	3662	23151
Standard Deviation	2594	15284	2756.542	11662.18	2050.379	9411.704
Sample Variance	6730401	2.34E+08	7598524	1.36E+08	4204053	88580179
Range	15332	70767	11473.4	58566	10536.9	46330
Count	52	40	46	42	52	47
Confidence Level (95.0%)	722	4888	818	3634	570	2763
Mean plus 3 SDs	11350	65357	13498	68795	10204	52342
Mean minus 3 SDs	-4215	-22273	-3040	-1177	-2097	-4127

As is shown in the table none of the consumption records fell below three standard deviations from the mean and only one dwelling (in Leicester) had an electricity consumption figure above four standard deviations from the mean. As no gas consumption figure was available for this dwelling it was impossible to infer whether or not this constituted a real outlier or whether the household were particularly high energy consumers.

4.13. Chapter Summary

This chapter has outlined the main descriptive statistics calculated for the three study areas and highlighted the similarities and differences between the statistics for these samples and those for the local area or the UK as a whole. This is useful in providing a context for interpreting the results of the more detailed analyses covered in the chapters to follow.

Chapter 5. Analytical Techniques

5.1. Introduction

This chapter describes the analytical techniques used for the exploratory and confirmatory analyses of the data collected from the energy questionnaire that could be matched with the floor area data from the GIS coverages and the annual consumption data obtained from the DTI.

Two step clustering, crosstabulation and simple linear regression were used for the exploratory analyses and multiple regression was used for the confirmatory analyses. Two step clustering is covered in detail as the accurate interpretation of the outputs from this technique involves considerable visual inspection of the supporting plots for each analysis. The correlation and significance measures used to interpret the results of crosstabulation of the data are defined. It is necessary to justify the treatment of some variables for clustering and crosstabulation; this is covered in section 5.3 and the use of the latter technique is described in section 5.4. The use of simple linear regression is covered in 5.5, and the use and interpretation of the results from the multiple regressions in section 5.6.

The use of stepwise regression was considered but rejected as an analytical technique to extract those variables with the strongest relationships to energy consumption and build models without the need for an intensive exploratory phase. This decision was justified by the weak relationships found between consumption and the majority of the variables in the datasets.

Further arguments against its use in studies such as this include the high risk of assigning high levels of significance to chance features of the data and redundant that bear no relation to established knowledge; its tendency to produce r^2 values that are biased towards being high and produces inaccurate p-values (referred to in this thesis either as p-values or ANOVA significance values) that are very difficult to correct for; and its difficulty in dealing with evidence of collinearity, which can be expected to emerge after the addition of only a small number of variables in small datasets such as these. These arguments are summarised from Mantel (1970) Copas (1983) Judd & McClelland (1989) Altman & Anderson (1989) Hurvich & Tsai (1990) Roecker (1991) Derksen & Keselman (1992) Tibshirani (1996) and Sribney (1998), and perhaps the most succinct is from Judd and McClelland:

"It is our experience and strong belief that better models and a better understanding of one's data result from focussed data analysis, guided by substantive theory."

Judd & McClelland, 1989, p.204

All analyses reported in this thesis were performed using Excel or SPSS (versions 12.0 and 14.0*) and unless stated otherwise SPSS definitions of the various tests are used. Excel was used for the descriptive statistics and simple linear regressions due to the greater flexibility for manipulating tables in spreadsheet format. SPSS was used for all other analyses.

5.2. Two step cluster analysis

To date the use of two step clustering is uncommon in this field and therefore this section provides an overview of the technique as applied to this study. A full treatment of two step clustering can be found in Sambamoorthi (2006) and Hamburg University (2006).

Two step is a form of hierarchical clustering and has the key benefit that it can be used on both continuous and categorical data, which was essential for most of the analyses. The term 'two step' comes from the fact that the technique initially pre-clusters the records and then applies conventional hierarchical clustering to produce a number of clusters that are either automatically defined or pre-determined. At first both options, automatic and pre-determination of the number of output clusters, were used, however even at this early stage it was

* This was due to a university-wide upgrade and was unintentional. In light of this all analyses for which tables and plots are reported in this thesis were reproduced using version 14.0.

found that no more than two or three clusters could be produced by each analysis and automatic determination was used in all subsequent analyses.

The goodness of fit measure used for clustering was Schwarz's Information Criterion (SIC, also known as the Bayesian Information Criterion because Schwarz used a Bayesian argument for using it) which is based on a basic log-linear measure of probability (Weakliem, 1999 and SPSS). The alternative option for two step is the Akaike Information Criterion (AIC) which was inappropriate in this case as it is mainly used for the clustering of econometric data (About: Economics, 2007).

Two distance measures are available for use with two step clustering within SPSS, Euclidean or log-linear. Log-linear was used for these analyses as Euclidean is not suitable for clustering categorical data.

Where clusters are described in the discussion some of the results are limited to the most relevant outputs. This is simply because the full outputs are too extensive to justify their inclusion in their entirety for every analysis. The remainder of this section provides an overview of the output tables and plots taken from a single analysis conducted on the data from the Leicester sample early in the data analysis phase of the study.

5.2.1. Cluster distribution, profile and frequency tables

The cluster distribution tables (Table 5.1) give the number of records in each cluster and the number excluded from the analysis. Any records which are not complete for all the variables being clustered are excluded.

The cluster profile (or centroid) tables (Table 5.2) give the means and standard deviations for the continuous variables. In some cases the standard deviations for the clusters suggest a degree of overlapping between the clusters which is not significant at the 95% confidence level. This can be confirmed by inspecting the simultaneous 95% confidence interval plots for these variables (see Figures 5.1 and 5.2).

The cluster frequency tables (Table 5.3) give the composition of each cluster by the categorical variables. The same tables are also produced from crosstabulation of the data.

Table 5.1. Example of a cluster distribution table

		N	% of Combined	% of Total
Cluster	1	23	48.9%	43.4%
	2	24	51.1%	45.3%
	Combined	47	100.0%	88.7%
Excluded Cases		6		11.3%
Total		53		100.0%

Table 5.2. Example of a cluster profile (or centroid) table

			ElecTot	TFA	Total Number of Occupants
Cluster	1	Mean	4503.6957	165.6174	2.43
		Std. Deviation	3066.14047	64.16179	1.037
	2	Mean	2769.6917	89.0433	1.63
		Std. Deviation	1864.30004	19.59000	.924
	Combined	Mean	3618.2468	126.5157	2.02
		Std. Deviation	2646.07778	60.48010	1.053

Table 5.3. Example of a cluster frequency table (for the number of bedrooms)

			2	3	4	5
Cluster	1	Frequency	0	14	7	2
		Percent	.0%	100.0%	100.0%	100.0%
	2	Frequency	24	0	0	0
		Percent	100.0%	.0%	.0%	.0%
	Combined	Frequency	24	14	7	2
		Percent	100.0%	100.0%	100.0%	100.0%

5.2.2. Simultaneous 95% confidence interval plots

These plots show the 95% confidence intervals for the means for the continuous variables being clustered and aid the interpretation of the cluster profile tables. Figure 5.1 shows that for this analysis the clusters were not distinct by electricity consumption but Figure 5.2 shows that they were distinct by total floor area (TFA).

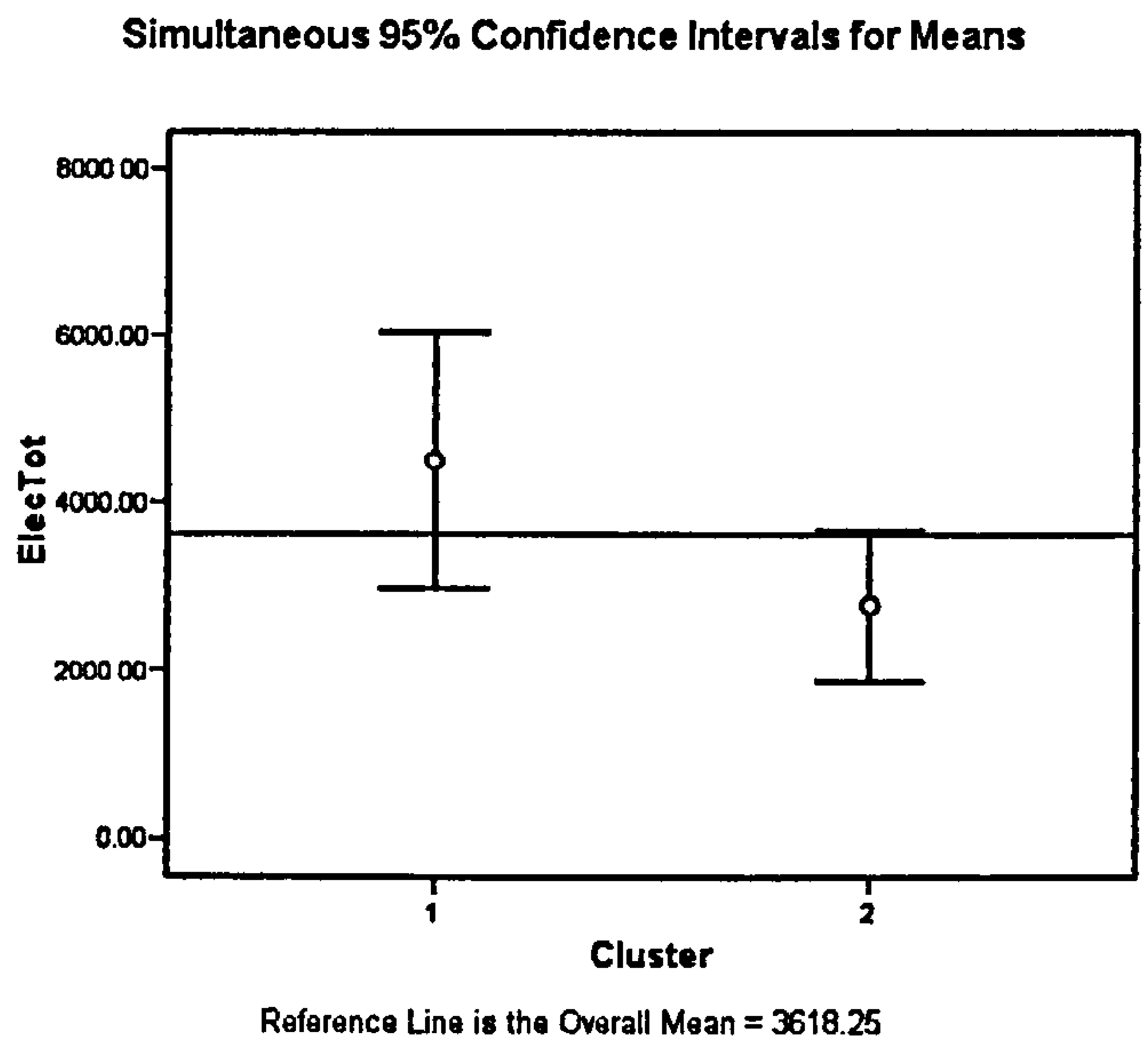


Figure 5.1. Example of a simultaneous 95% confidence interval plot

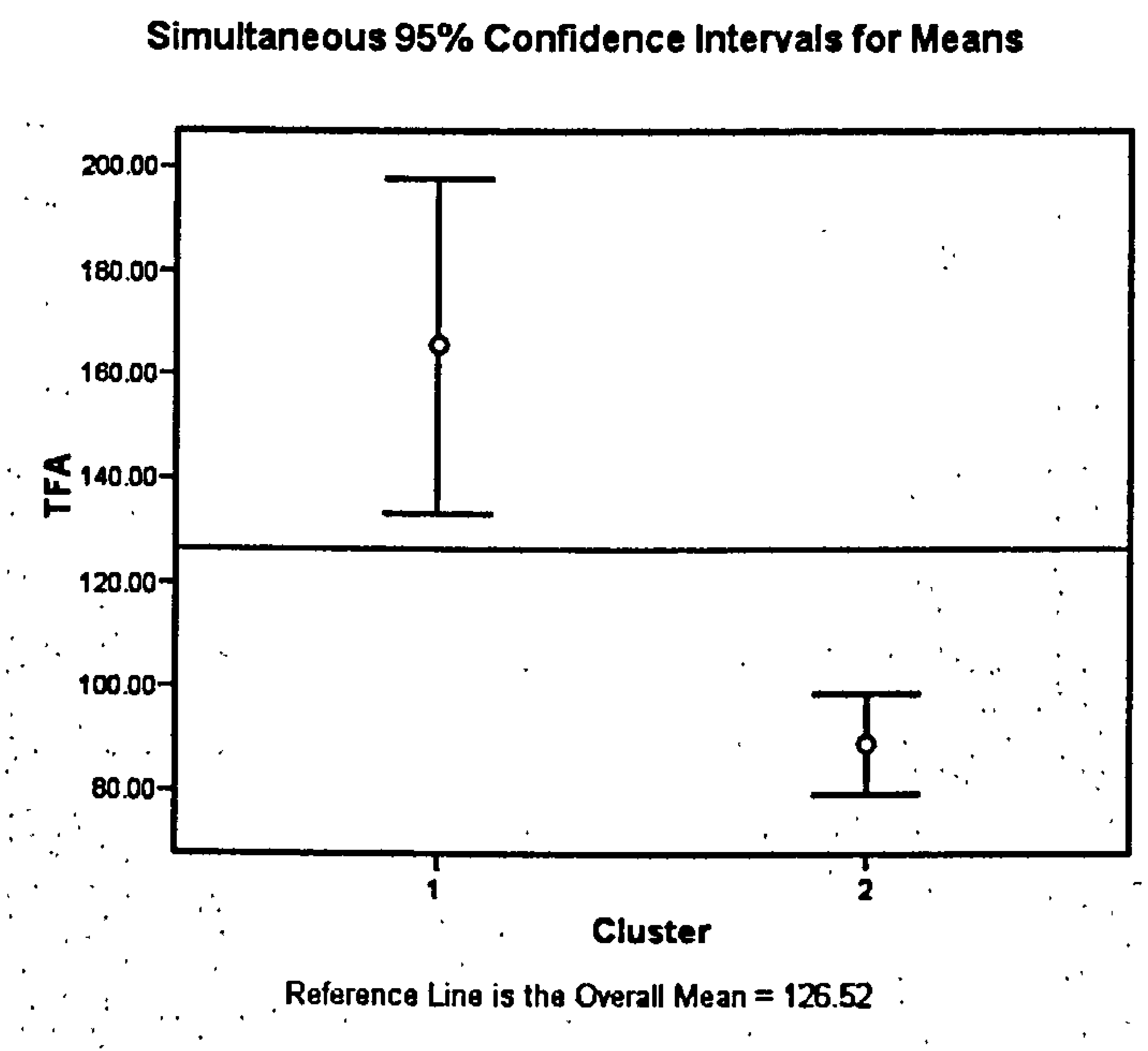


Figure 5.2. Example of a simultaneous 95% confidence interval plot (2)

5.2.3. Within cluster percentage plots

These plots (Figures 5.3 and 5.4) illustrate the composition of the clusters by the categorical variables. The main benefit of these plots is that the provide a visual means of interpreting the results of clustering that can highlight distributions that may not be immediately evident from inspection of the cluster frequency tables.

In Figure 5.3 the difference in the numbers of bedrooms for the dwellings in each cluster is clear. This difference is less evident for the number of rooms (Figure 5.4). These plots are particularly useful for monitoring whether the composition of a set of clusters by a categorical variable is converging or diverging as variables are introduced or removed. Similar plots can also be output from crosstabulation with clustered data, for which they can provide additional evidence to support or reject a correlation between the cluster number and the variables in question.

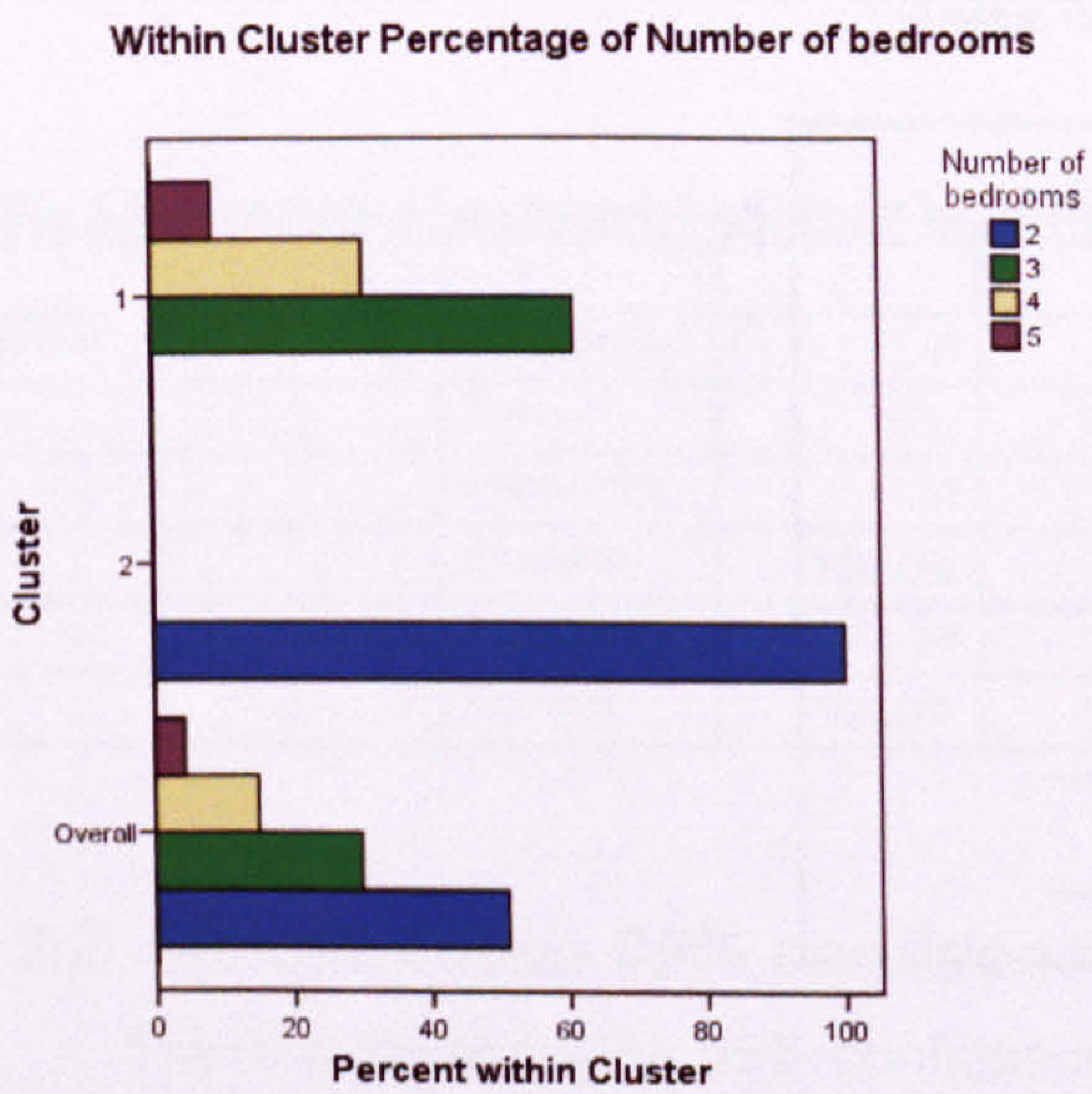


Figure 5.3. Example of a Within Cluster Percentage Plot

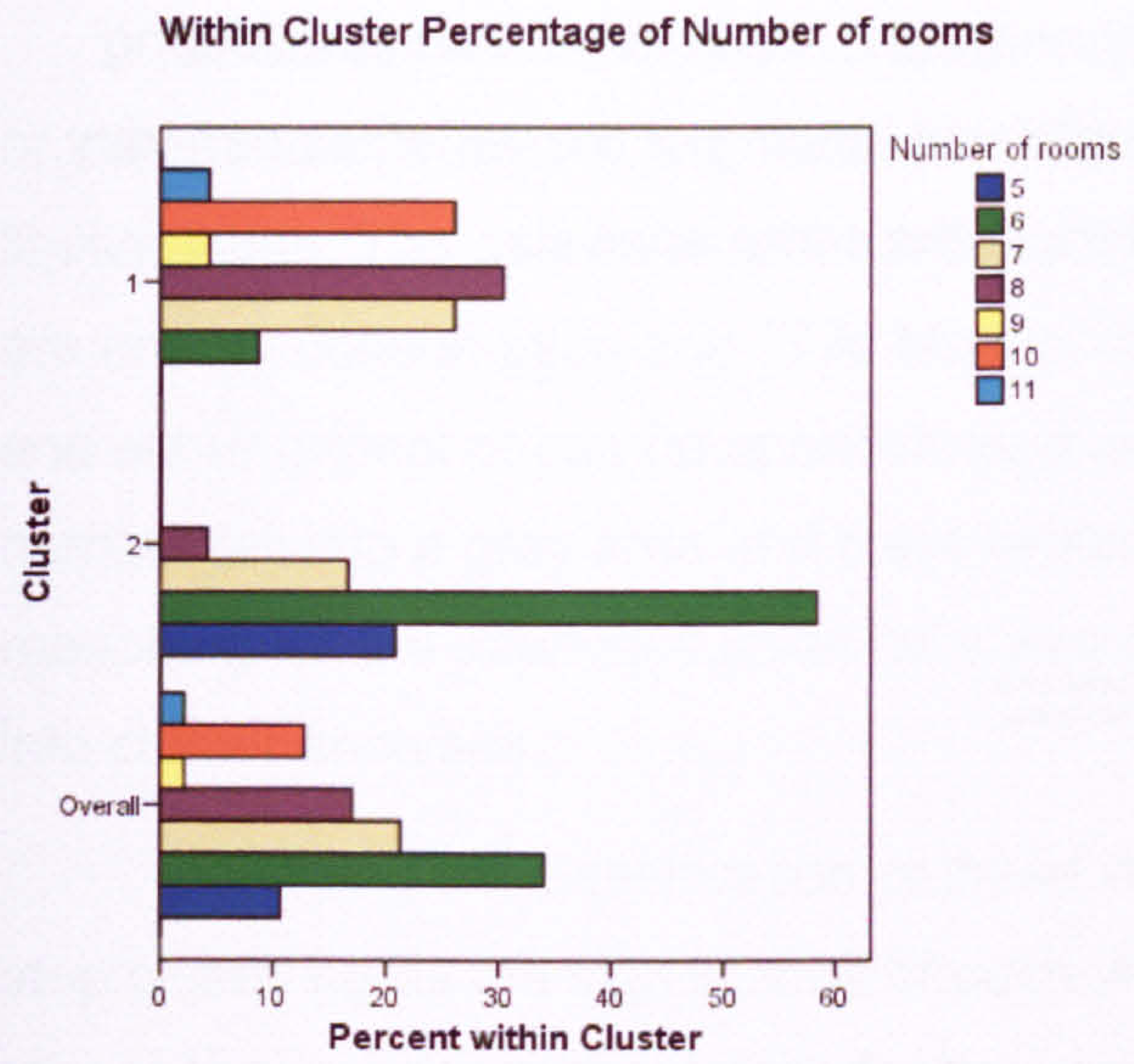


Figure 5.4. Example of a Within Cluster Percentage Plot (2)

5.2.4. Categorical and continuous variablewise importance plots

These plots illustrate the importance of a variable in determining the clusters, using the chi-square test for categorical variables (Figure 5.5) and the Student's t-test for continuous variables (Figure 5.6). The blue and green lines mark the critical value for each variable that must be exceeded in order to conclude that the variable was critical for determining the clusters. The plots for the categorical variables are uni-directional, whereas those for the continuous variables are bi-directional and show whether each cluster was determined by selecting records with values higher or lower than the mean for the dataset.

Variables shown to have significances that do not exceed the critical value do not necessarily have no impact whatsoever on determining the clusters, but if so this will be minor. These plots are used to rank the variables or the clusters (from top to bottom) in terms of their significance. Only the former are included in this thesis as the focus of the study is on determining the significance of the variables. In the latter case the plots would be output by variable and those clusters with smaller standard deviations for the variables would be ranked higher.

It should be noted that in many analyses, especially those considering larger numbers of variables, the strength and ranking of the variables can vary, sometimes drastically, between clusters in the same analysis.

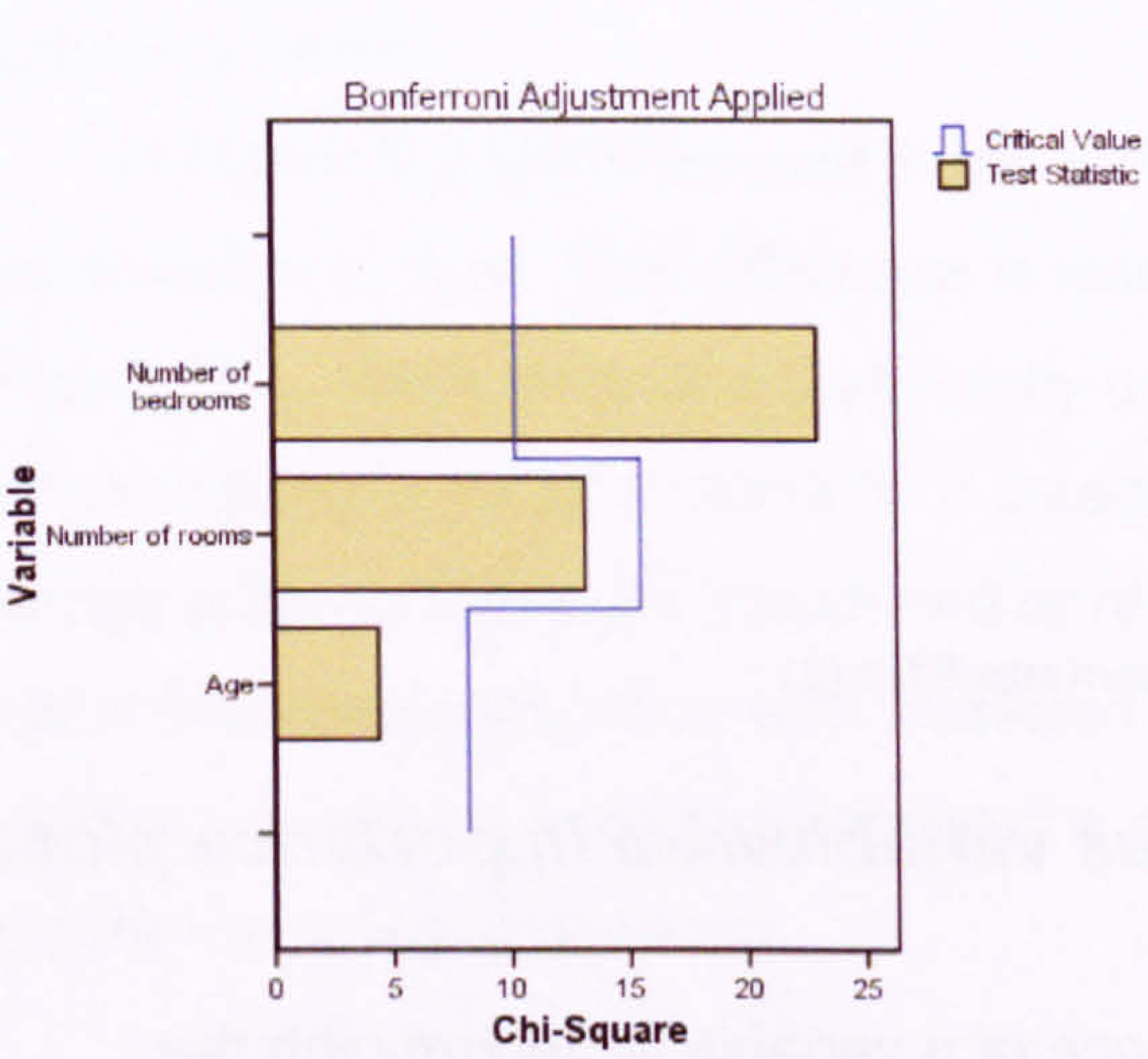


Figure 5.5. Example of a categorical variablewise importance plot

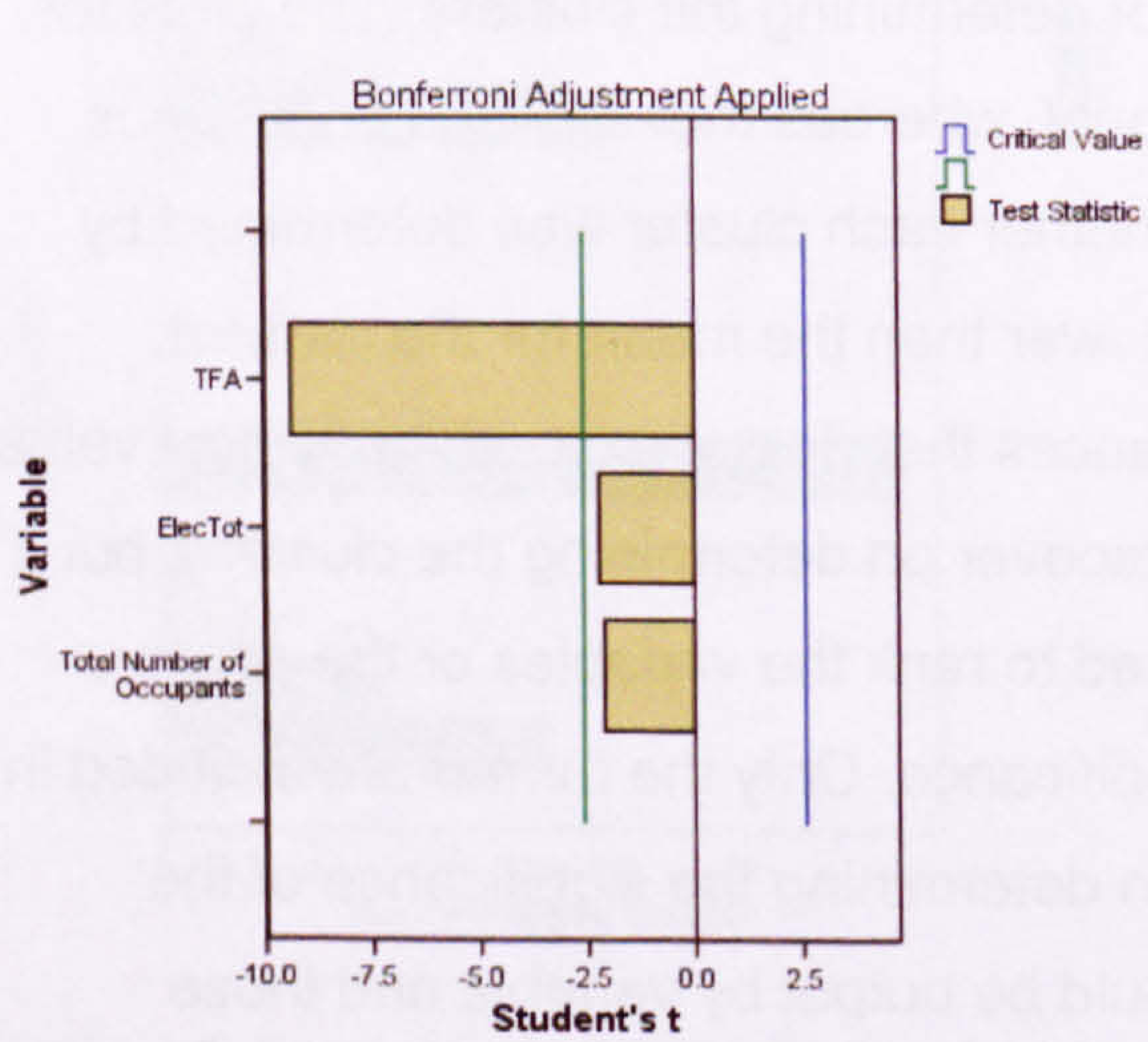


Figure 5.6 Example of a continuous variablewise importance plot

5.3. Treatment of variables for two step clustering

SPSS splits variables used for two step clustering into either 'continuous' or 'categorical', however this distinction is in some cases rather arbitrary and of limited value. The only true continuous variables analysed as part of this study are energy consumption and TFA. Most of the remainder are clearly categorical, and either ordinal or can be approximated as being ordinal. However a small number fall into a grey area and merit explanation of the way they are used. The reasoning for the examples given here was applied to all such variables entered into cluster analyses.

Justifying the classification of these variables is important when using two step clustering as the significance of each variable in determining the clusters is shown by separate output tables for the variable types (Figures 5.5 and 5.6) and the different significance tests used are not directly comparable. Therefore it is usually impossible to state with a high degree of certainty if a variable ranked highest on a continuous variablewise importance plot is more or less important than the highest ranked variable on the associated categorical variablewise importance plot. The exception to this being when the critical value for one variable is close to 0 and its significance is high and the opposite is true for a variable of the same ranking on the other plot.

Total occupancy is a discrete ordinal variable, however in reality people are not discrete homogeneous units, and therefore one person in one household does not have exactly the same impact on household energy consumption as another person in another household. Furthermore, this variable also includes children and applies the same value (1) to a child as to an adult. There is also an argument that children should be given a value lower than 1, however with no conclusive evidence from previously published work as to how much domestic energy use children are responsible for compared to adults it is impossible to determine an accurate and justifiable weighting. This initial decision to apply an equal value to adults and children was supported by the results from exploratory analyses of the data and is discussed further in Chapter 6 section 6.3.

Conversely the numbers of rooms and bedrooms, two variables that are also discrete and approximately ordinal, have been classified here as 'categorical'. Again this is mainly due to the common convention that dwellings are often categorised by these variables. However, a further justification for this in that both effectively have upper limits imposed by dwelling size and a lower limit imposed by fitness for purpose, for example a bedroom has to be big enough for at least a single bed and a kitchen has to be big enough to contain basic appliances.

These limitations mean that the variables lend themselves more for treatment as 'categorical' variables than 'continuous' ones, and for the purposes of interpreting the results has the benefit of allowing the output of within cluster percentage plots showing differences in cluster composition.

5.4. Crosstabulation

Crosstabulation is a simple yet very useful means of inspecting the frequency distributions of the variables. It is also used to tabulate the composition of clusters and correlate clusters with other variables and is used extensively in this thesis. Where ordinal data, or data that can be approximated as ordinal, is being analysed the Spearman correlation (similar to the Pearson correlation but specifically for ordinal data) is used to indicate the strength of the relationship. An approximated significance value below 0.05 indicates that the relationship is highly statistically significant.

The consumption and floor area data are continuous, and therefore could not be crosstabulated directly with other variables. In order to analyse the relationships between the variables and energy consumption using crosstabulation the Visual Bander function in SPSS was used to band the data into five bands, each representing 20% of the records. This gave approximately 10 records in each band for the individual datasets and approximately 30 records in each band for the combined dataset. This was justifiable as the data were approximately normally distributed. Where significant correlations were found they were validated using multiple regression (chapter 8).

5.5. Use of simple linear regression

As well as clustering, simple linear regression was used as part of the exploratory analysis phase of the study. For this the records were categorised according to differences in a wide range of variables known or suspected to influence domestic energy consumption. For variables with small numbers of outcomes this was done by regressing both sets of energy consumption data with TFA within each group, for example the records were split into those households for which homeworking was reported and those for which it wasn't. Where the range of responses produced too few records for an analysis to be meaningful, e.g. composition of households based on employment, the categorisation was restricted to the most numerous groups in each study area.

Within each category the electricity and gas consumption data were regressed against TFA and the resulting r^2 values used to identify the most promising variables for use in the more detailed analyses to follow. Any categorisations which clearly showed no correlations in every group were taken as indicative of variables to be rejected. Those which showed some level of correlation in one group were flagged as potentially significant, and those showing clear correlations in more than one group were prioritised for further analysis.

For some ordinal variables, e.g. the number of energy efficient light bulbs in use, the range of responses was sufficient to merit regression directly against energy consumption as these variables had the potential to be direct indicators of differences in consumption should any correlations be found. The plots produced from each regression were also visually inspected for scatter and distributions that appeared most consistent or inconsistent with the r^2 values were noted.

The rule of thumb adopted for interpreting the results of the simple linear regressions reported in this thesis is that r^2 values above 0.5 indicate the most promising variables for further analysis, whilst those producing r^2 values between 0.25 and 0.5 were considered interesting enough to be weighed against other factors. This strategy reflects a realistic view that the dataset was not large enough to be sufficiently representative to form the basis for a model based on all the captured variables. The r^2 values for these regressions are summarised in Appendix 7. In practice the correlations produced in this study were generally weak and visual inspection of the scatter plots was needed in more cases than not. This in itself a justification of the decision not to opt to use stepwise regression on the data, however there are stronger arguments against opting for this approach and in favour of the more 'hands-on' (and significantly more time consuming) use of simple linear regression for the exploratory analyses and multiple regression for the confirmatory analyses.

5.6. Multiple Regression Analysis

Multiple regression was used as a confirmatory technique to determine the collective extent to which variables from the datasets explained the variances in energy consumption and the statistical significances in each case. As the ratio of number of records to the number of variables was small an iterative approach was adopted. Each additional variable was added individually and the full outputs inspected for the levels of each correlation with both the dependent variable (electricity or gas consumption) and with the other variables in the analysis. Particular attention was paid in each case to the number of records in each analysis, Pearson correlation coefficients, r^2 values, adjusted r^2 values, the change in the F statistic attributed to the new variable, and the significance value (also called the p-value) of the ANOVA results.

The Pearson correlation coefficient shows the strength and direction of a correlation between two variables and was used as a simple assessment of whether or not each new variable was behaving as expected. The r^2 value gives the overall correlation between the dependent (consumption) and independent variables, however at the higher levels of dimensionality found in studies such as this the adjusted r^2 value becomes more important as it compensates for the rigidity of the r^2 value by adjusting for the number of predictors[6]. This is a particularly useful statistic when building up multiple regressions as the change in this statistic is a measure of the additional explanatory power of the new variable. The ANOVA significance value was used as the main test of the cumulative significance of the variables, with a value less than 0.05 indicating the highest level of significance and a value between 0.05 and 0.1 indicating a weaker significance. The same rules apply to the interpretation of the change in the F statistic.

The outputs were studied for evidence of collinearity, the normality of the plots of standardised residuals, and the plot of cumulative versus observed probability. The collinearity statistic reported in this thesis is the condition index, which is the square root of the ratio of the largest eigenvalue to the corresponding eigenvalue associated with each variable in a multiple regression. In reality the eignenvalues were inspected, however the condition index is easier to interpret and can be reported simply as a single statistic. A condition index above 15 denotes a possible problem with collinearity and above 30 a serious problem with collinearity.

Summary definitions of the statistics quoted for the analyses are given in the glossary of statistical terms.

5.7. Chapter summary

This chapter has described and justified the statistical techniques used for the analysis of the data collected as part of this study, and also the reasoning against using stepwise regression for the exploratory work. The principal techniques used for the exploratory analyses to follow are two-step clustering and simple linear regression, with multiple regression for the confirmatory analyses. The interpretation of the full outputs from two-step regression have been covered in detail as these are only included later where a full discussion of

[6] Adjusted r^2 is particularly relevant where variables are added to a regression as it can decrease, whereas r^2 cannot.

the profiles of the clusters found within the data is merited. The use of the condition index as the statistical test for evidence of collinearity, a problem that can be expected to occur in datasets such as this, has also been justified.

Chapter 6. Discovering Groups of Energy Consumers Using Cluster Analysis

6.1. Introduction

This chapter describes the use of two step cluster analysis as an exploratory technique to attempt to identify distinct groups of energy consumers in the combined dataset. It assesses the evidence for a direct or indirect relationship between the clusters and built form type.

Sections 6.2 to 6.5 describe the cluster analysis of the consumption data and the crosstabulation of the clusters discovered by the analyses with built form type and the other variables in the dataset. The procedure is repeated to establish which variables are useful in explaining differences in consumption within the study areas (sections 6.6 to 6.7). Those variables found to be most significant are then clustered with the consumption data and the resulting clusters related to built form type (section 6.8).

6.2. Energy consumption clusters

Two step clustering was performed using the consumption data for the combined dataset to establish whether distinct groups of energy consumers could be identified (see section 5.2 for an overview of two step clustering and an explanation of the tests and statistics used in this chapter).

Clustering on electricity and gas consumption produced three clusters that were distinct by both gas and electricity consumption. The cluster profiles giving the mean and standard deviation for these variables are in Table 6.1. The distribution of the clusters (Table 6.2) shows that each was composed of sufficient numbers of records to be a meaningful grouping. The 30 excluded records were those for which only one type of consumption data (electricity or gas) was available. The results show that at the 95% confidence level the three clusters represent distinct groups of consumers of both electricity (Figure 6.1) and gas (Figure 6.2).

Table 6.1. Cluster profiles for energy consumption in the combined dataset

		ElecTot		GasTot	
		Mean	Std. Deviation	Mean	Std. Deviation
Cluster	1	7581.3731	2381.76442	40598.9231	14565.49078
	2	4138.3018	1135.83640	28341.4821	5465.63029
	3	2310.2738	918.91640	15464.9286	6412.37754
	Combined	4241.0653	2376.48056	26550.1774	12462.96511

Table 6.2. Cluster distribution for the combined dataset

		N	% of Combined	% of Total
Cluster	1	26	21.0%	16.9%
	2	56	45.2%	36.4%
	3	42	33.9%	27.3%
	Combined	124	100.0%	80.5%
Excluded Cases		30		19.5%
Total		154		100.0%

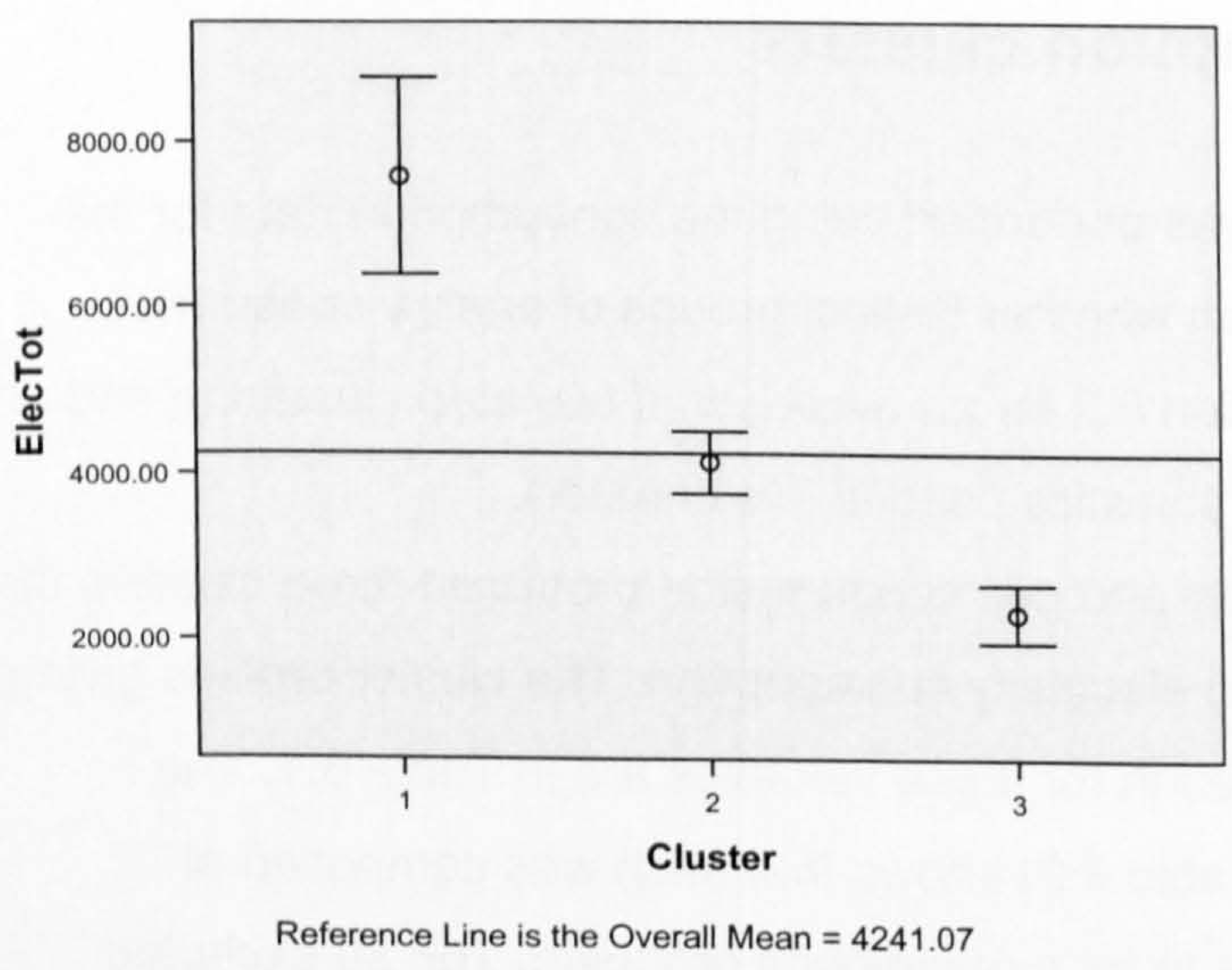


Figure 6.1. Plot of the simultaneous 95% confidence intervals for the means for electricity consumption for the energy consumption clusters in the combined dataset

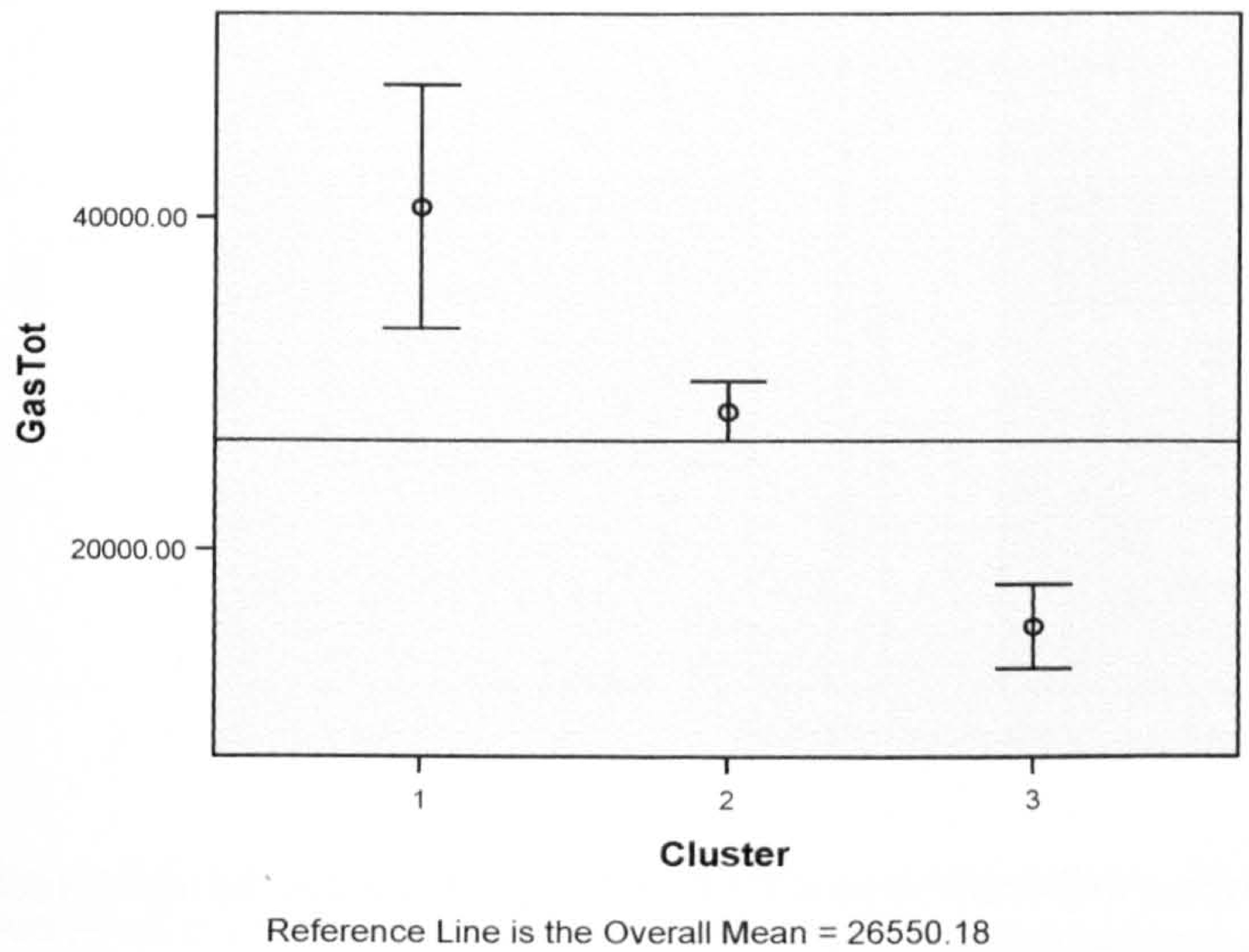


Figure 6.2. Plot of the simultaneous 95% confidence intervals the means for gas consumption for the energy consumption clusters in the combined dataset

The supporting variablewise importance plots (Figures 6.3 to 6.5) show that the upper and lower clusters were determined by higher and lower consumption of both electricity and gas, with electricity being the higher ranked determining variable. The middle cluster was defined by higher gas consumption, which exceeded the critical value for determining the clusters, whereas electricity consumption was lower than average for this group but not significant enough to exceed the critical value.

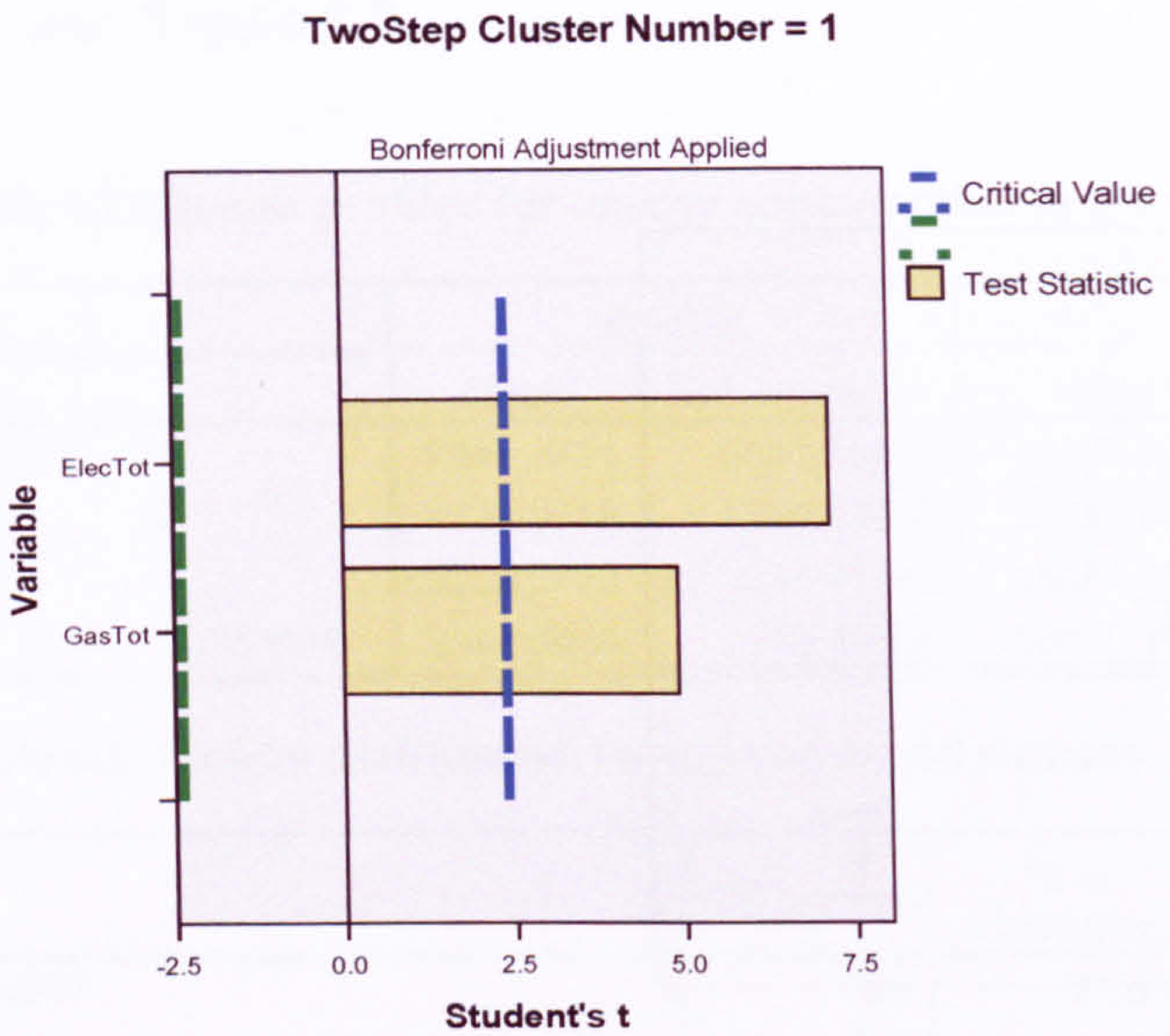


Figure 6.3. Continuous variablewise importance plot for Cluster 1 for the combined dataset clustered on electricity and gas consumption

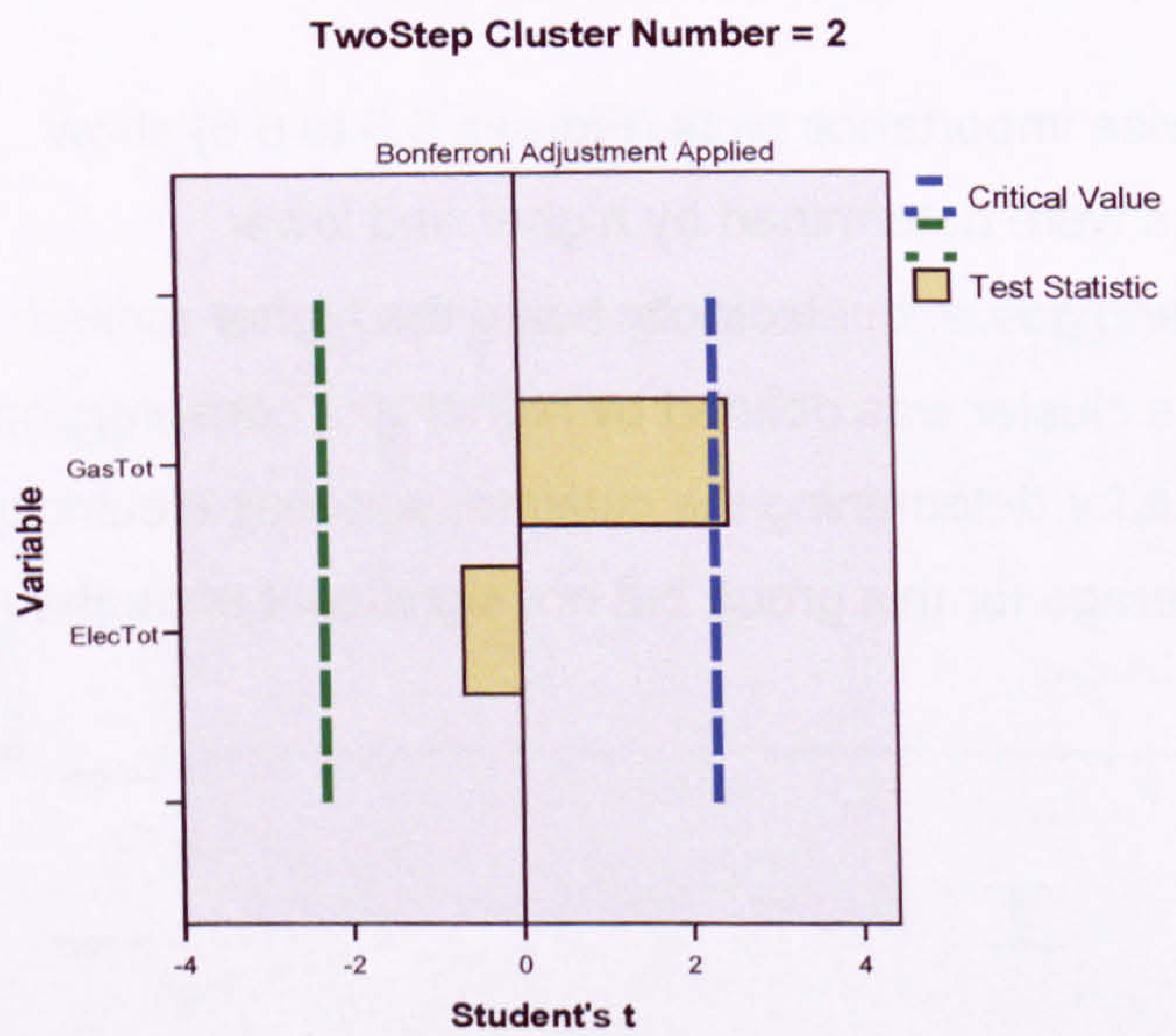


Figure 6.4. Continuous variablewise importance plot for Cluster 2 for the combined dataset clustered on electricity and gas consumption

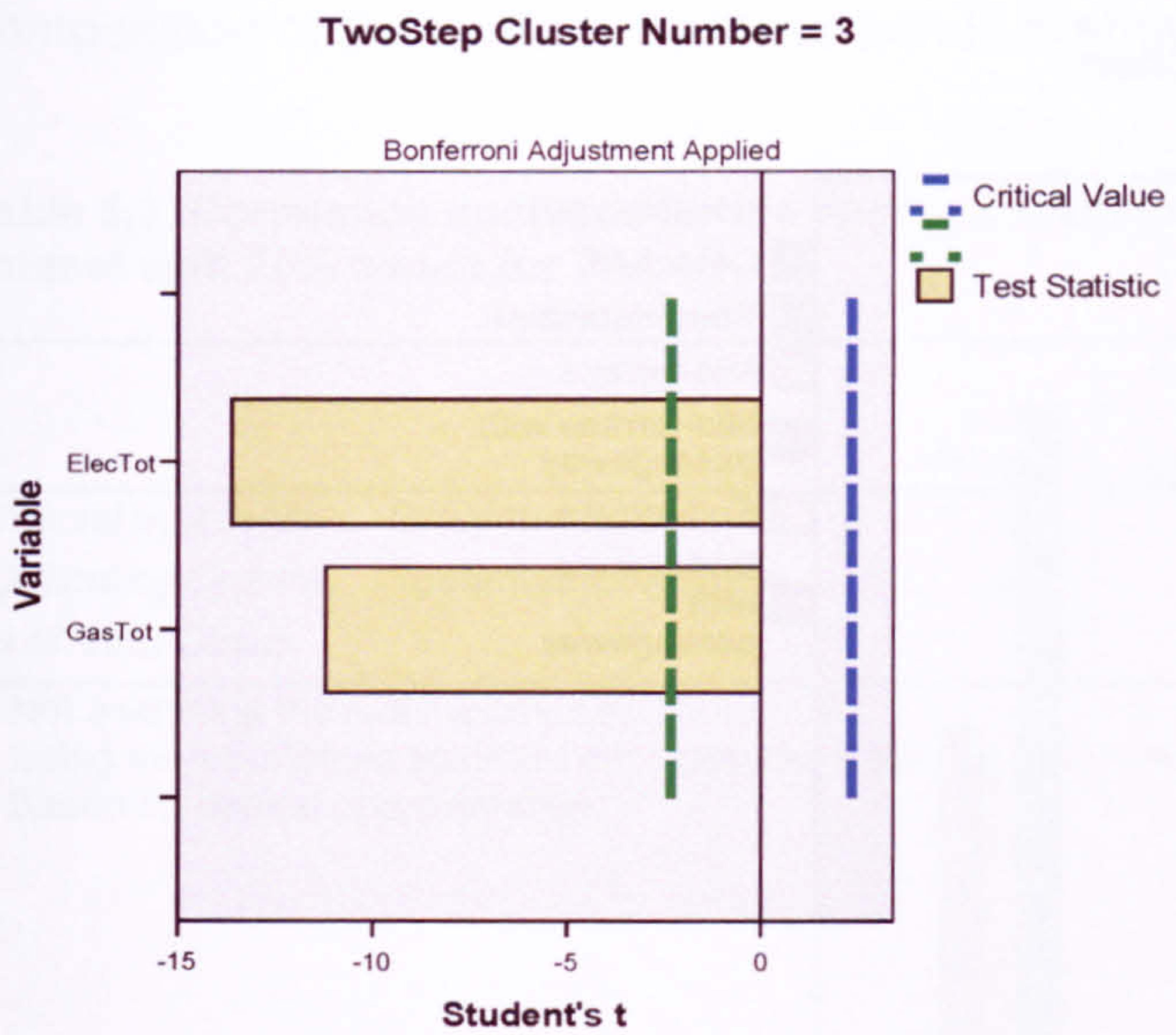


Figure 6.5. Continuous variablewise importance plot for Cluster 3 for the combined dataset clustered on electricity and gas consumption

6.3. Composition of the clusters by built form type

The clusters were investigated for composition by built form type to determine if this was a factor in determining the clusters, and later if it was an underlying influence being expressed by the most significant determining variables (section 6.6). Crosstabulation of the clusters with built form type showed that whilst most detached dwellings belonged to 1 and 2 and most semis belonged to clusters and 3 (Figure 6.6) there was not sufficient evidence to conclude that the clusters were centred on built form type. However, it is notable that both the end-terrace groups and most of the detached group fall into the higher and medium consuming clusters whereas the semis and mid-terraces are biased towards the medium and lower consuming clusters. This may bear some relation to differences in exposed wall areas.

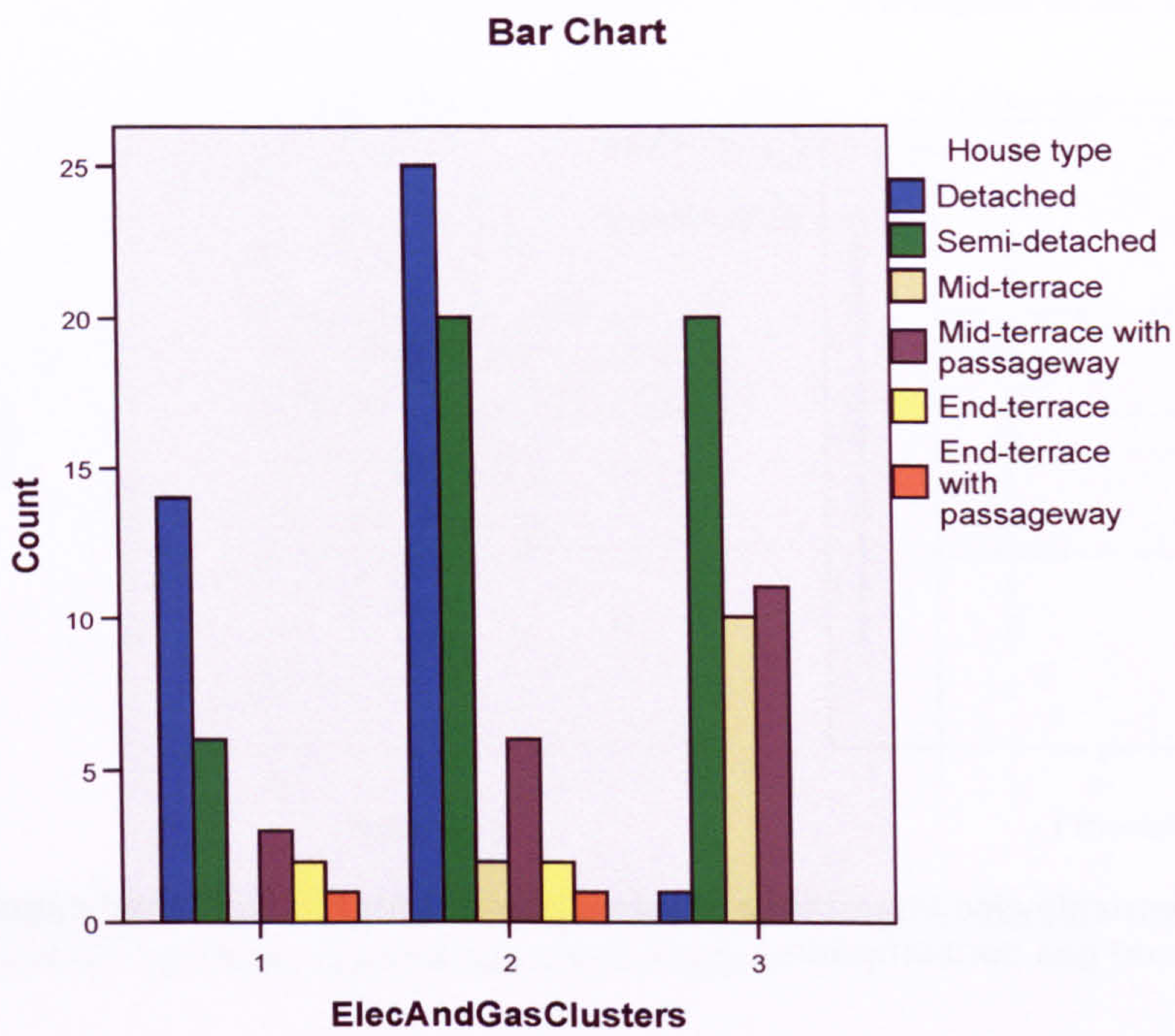


Figure 6.6. Composition by built form type of the clusters for energy consumption in the combined dataset

6.4. Composition of clusters by TFA, occupancy, dwelling age, numbers of rooms and numbers of bedrooms

When the variables in the dataset were crosstabulated with the energy consumption clusters the most significant results were found for the banded total floor area (TFA) data, occupancy, dwelling age and the numbers of rooms and bedrooms.

The total floor area of a dwelling is an indicator of its energy consumption that is now incorporated into the 2006 revision of the UK building regulations as a factor in calculating the Dwelling Carbon Dioxide Emission Rate (Carbon Trust, 2006). As a continuous variable the simplest way of crosstabulating it with the clusters for energy consumption was to band the data. The data was split into five bands, each containing 20% of the records (approximately 30 records in each). The Spearman correlation given in Table 6.3 confirmed that at a strong relationship was found between the clusters and the banded TFA data. The composition of the clusters by these bands is shown in Figure 6.7.

Table 6.3. Correlation statistics for the energy consumption clusters in the combined dataset with 20% bands for TFA

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.485	.071	-6.124	.000(c)
Ordinal by Ordinal	Spearman Correlation	-.492	.071	-6.241	.000(c)
N of Valid Cases		124			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

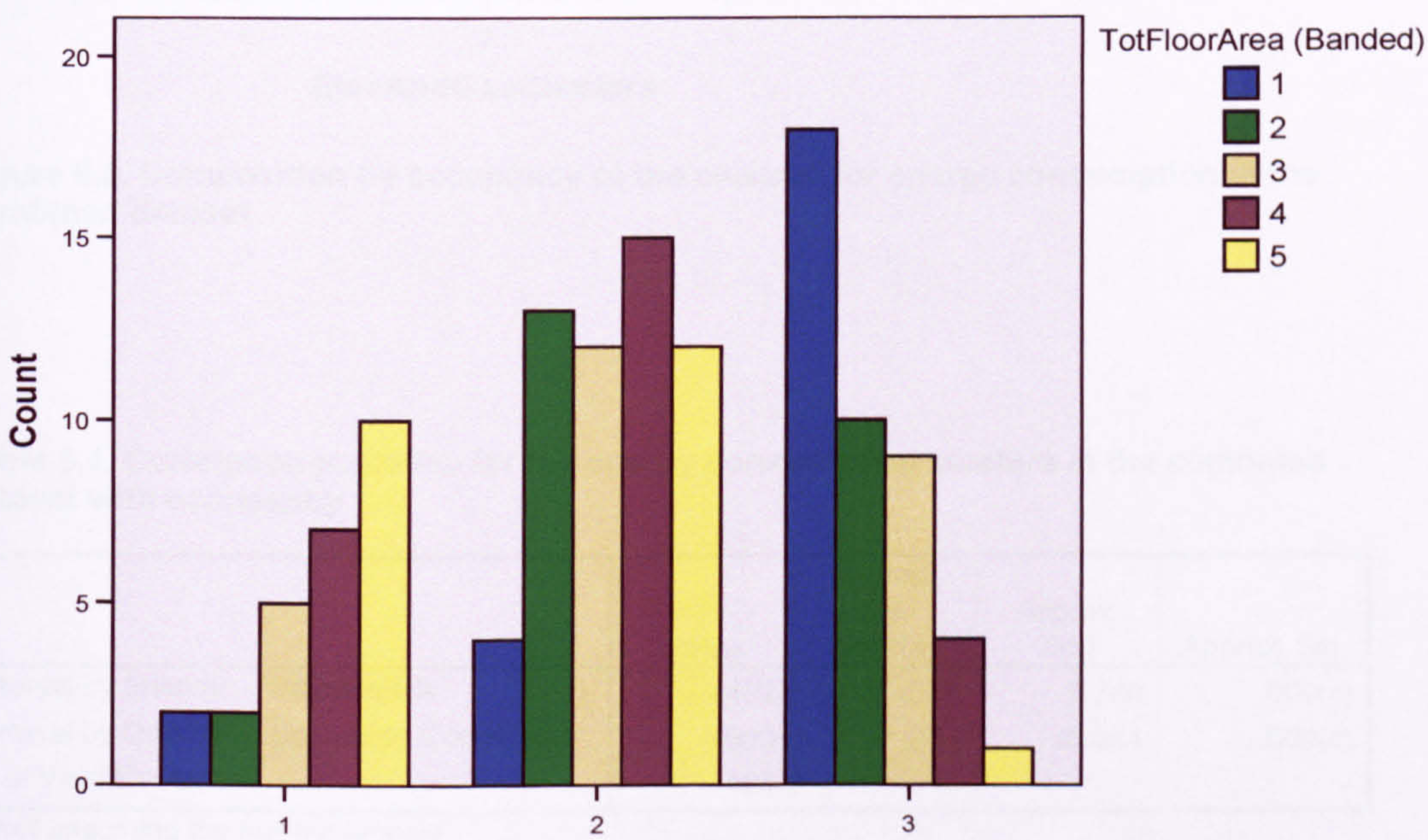


Figure 6.7. Composition by 20% bands for TFA of the clusters for energy consumption in the combined dataset

As discussed in chapter 4 section 4.2 this thesis treats occupancy as a continuous[7] variable for clustering and multiple regression analysis, however it can also be treated as an ordinal variable for the purpose of crosstabulation with the consumption clusters. This was done here to calculate the strength and significance of the relationship using the Pearson correlation.

The crosstabulation with the energy consumption clusters shows a clear relationship between higher consumption and higher occupancy. The composition of the clusters by occupancy is given in Figure 6.8. This shows a clear tendency towards single person households falling into the lowest consuming cluster and the larger households falling into the highest consuming cluster, with two person households being most common in the middle cluster. The summary statistics for this correlation (Table 6.4) show a relatively strong and highly significant Spearman correlation between the clusters and occupancy.

[7] This is SPSS nomenclature and is used here for simplicity. For two step clustering SPSS splits variables into 'continuous' and 'categorical'. Occupancy is actually a discrete ratio variable.

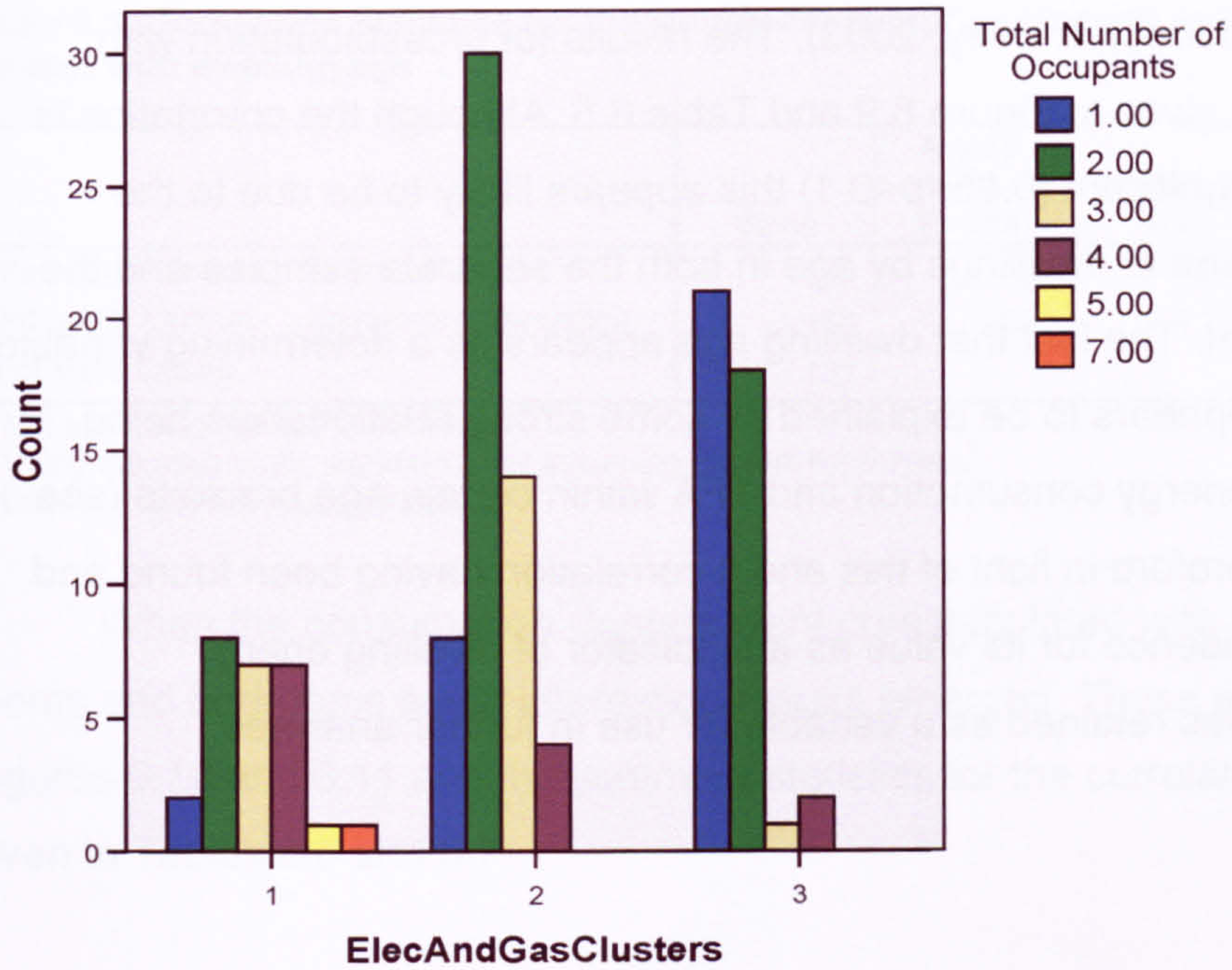


Figure 6.8. Composition by occupancy of the clusters for energy consumption in the combined dataset

Table 6.4. Correlation statistics for the energy consumption clusters in the combined dataset with occupancy

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.492	.070	-6.240	.000(c)
Ordinal by Ordinal	Spearman Correlation	-.500	.074	-6.384	.000(c)
N of Valid Cases		124			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

A strong and highly significant correlation found with the number of adults alone and a weak but still significant relationship with the number of children these were not as strong as for total occupancy. These results justified the use of total occupancy as the best measure of occupancy for use in these analyses.

Dwelling age is another established indicator of domestic energy consumption (Shorrock & Utley, 2003). The results for crosstabulation with dwelling age are given in Figure 6.9 and Table 6.5. Although the correlation is weak and less significant ($0.05<p<0.1$) this appears likely to be due to the unequal distribution of dwellings by age in both the separate samples and the combined dataset. The fact that dwelling age appears as a determining variable for the clusters appears to be explained by some strong relationships being found between energy consumption and TFA within certain age brackets (see section 7.5). Therefore in light of this and a correlation having been found and the published evidence for its value as an indicator of dwelling energy consumption it was retained as a variable for use in further analyses.

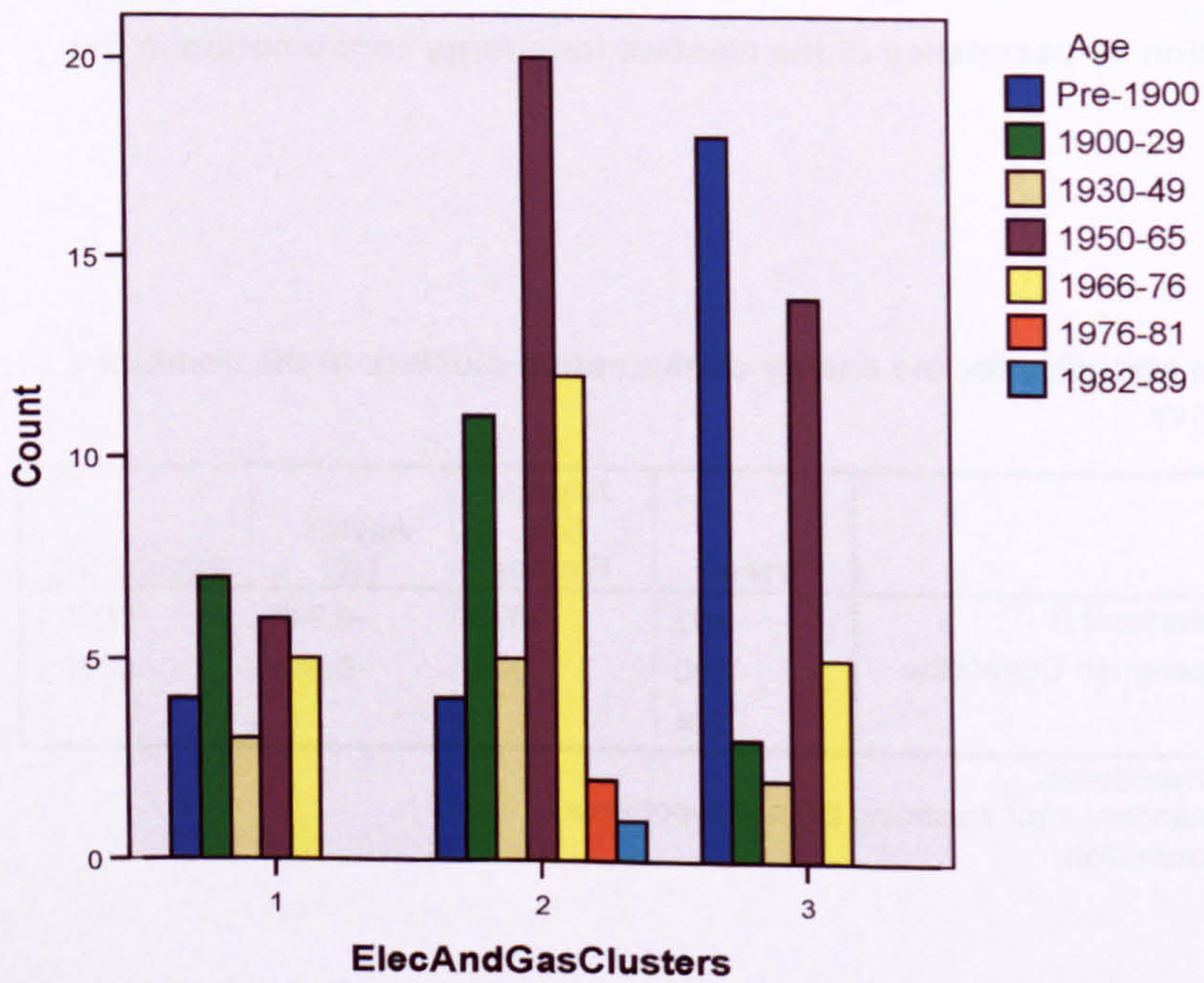


Figure 6.9. Composition of the clusters for energy consumption in the combined dataset by dwelling age

Table 6.5. Correlation statistics for the energy consumption clusters in the combined dataset with dwelling age

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.140	.089	-1.547	.124(c)
Ordinal by Ordinal	Spearman Correlation	-.159	.093	-1.768	.080(c)
N of Valid Cases		122			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

When the consumption clusters were crosstabulated with the numbers of rooms and bedrooms some interesting results emerged. These are illustrated in Figures 6.10 and 6.11 and the summary statistics for the correlations found are given in Tables 6.6 and 6.7.

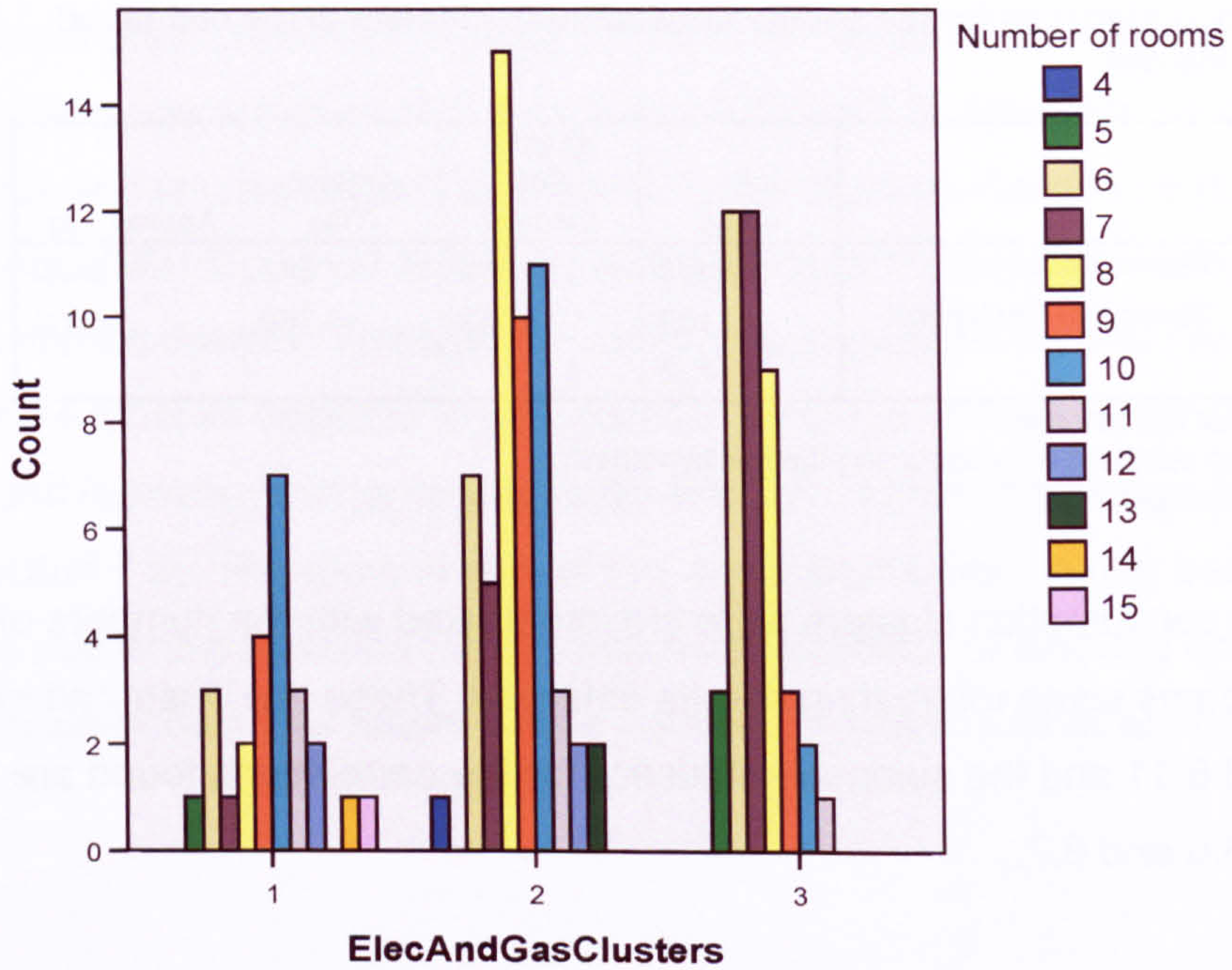


Figure 6.10. Composition by the number of rooms of the clusters for energy consumption in the combined dataset

Table 6.6. Correlation statistics for the energy consumption clusters in the combined dataset with the numbers of rooms

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.434	.076	-5.299	.000(c)
Ordinal by Ordinal	Spearman Correlation	-.443	.080	-5.429	.000(c)
N of Valid Cases		123			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

The composition of the clusters by the number of rooms shows quite clearly that dwellings with more rooms tend to be associates with highest consuming cluster and those with the least number of rooms to be associated with the lowest consuming cluster. The clearest distinction occurs either side of 8 to 10 room dwellings which are most common in the middle cluster.

The correlation with the number of rooms is strong and highly significant (Table 6.6).

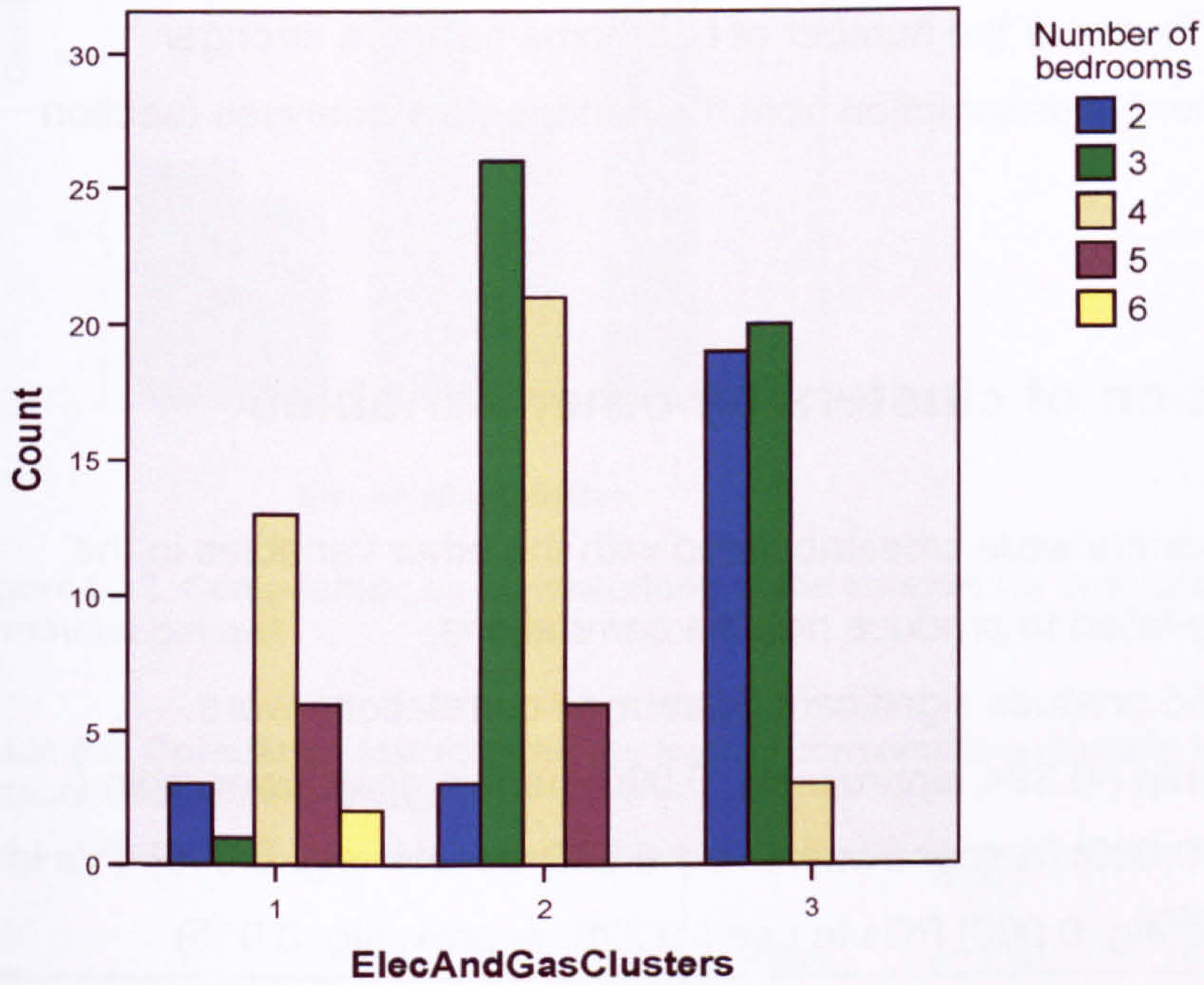


Figure 6.11. Composition by the number of bedrooms of the clusters for energy consumption in the combined dataset

Table 6.7. Correlation statistics for the energy consumption clusters in the combined dataset with the numbers of bedrooms

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.581	.067	-7.853	.000(c)
Ordinal by Ordinal	Spearman Correlation	-.591	.068	-8.049	.000(c)
N of Valid Cases		123			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

For the number of bedrooms there is a clear and highly significant correlation with the clusters that is notably stronger than with the numbers of rooms. The difference by this variable in the composition of the clusters is also much clearer, with 2 bedroom dwellings predominating in the lowest consuming cluster and those with 4 or 5 predominating in the highest consuming cluster. Although some doubt was cast on the relative strengths of these two relationships from the simple linear regression analyses (section 7.6) there was further evidence in favour of the number of bedrooms having a stronger relationship with energy consumption from the confirmatory analyses (section 8.3).

6.5. Composition of clusters by other variables

When the clusters were crosstabulated with the other variables in the dataset the majority failed to produce notable correlations.

Those that did produce significant Spearman correlations were dishwasher ownership (-0.394, approx. sig. 0.000) tumble dryer ownership (-0.334, approx. sig. 0.000) freezer ownership (-0.250, approx. sig. 0.005) TVs in use (-0.364, approx. sig. 0.000) PCs in use (-0.226, approx. sig. 0.015) microwave use (-0.258, approx. sig. 0.012) and homeworking. However, when used as clustering variables for the combined dataset (section 6.7) they were not found to reproduce the distinct clusters found for when the data was clustered on only gas and electricity consumption.

The composition of the clusters by homeworking, which shows a clear tendency towards households without homeworkers being lower energy consumers is given in Figure 6.12, and the correlation statistics in Table 6.8.

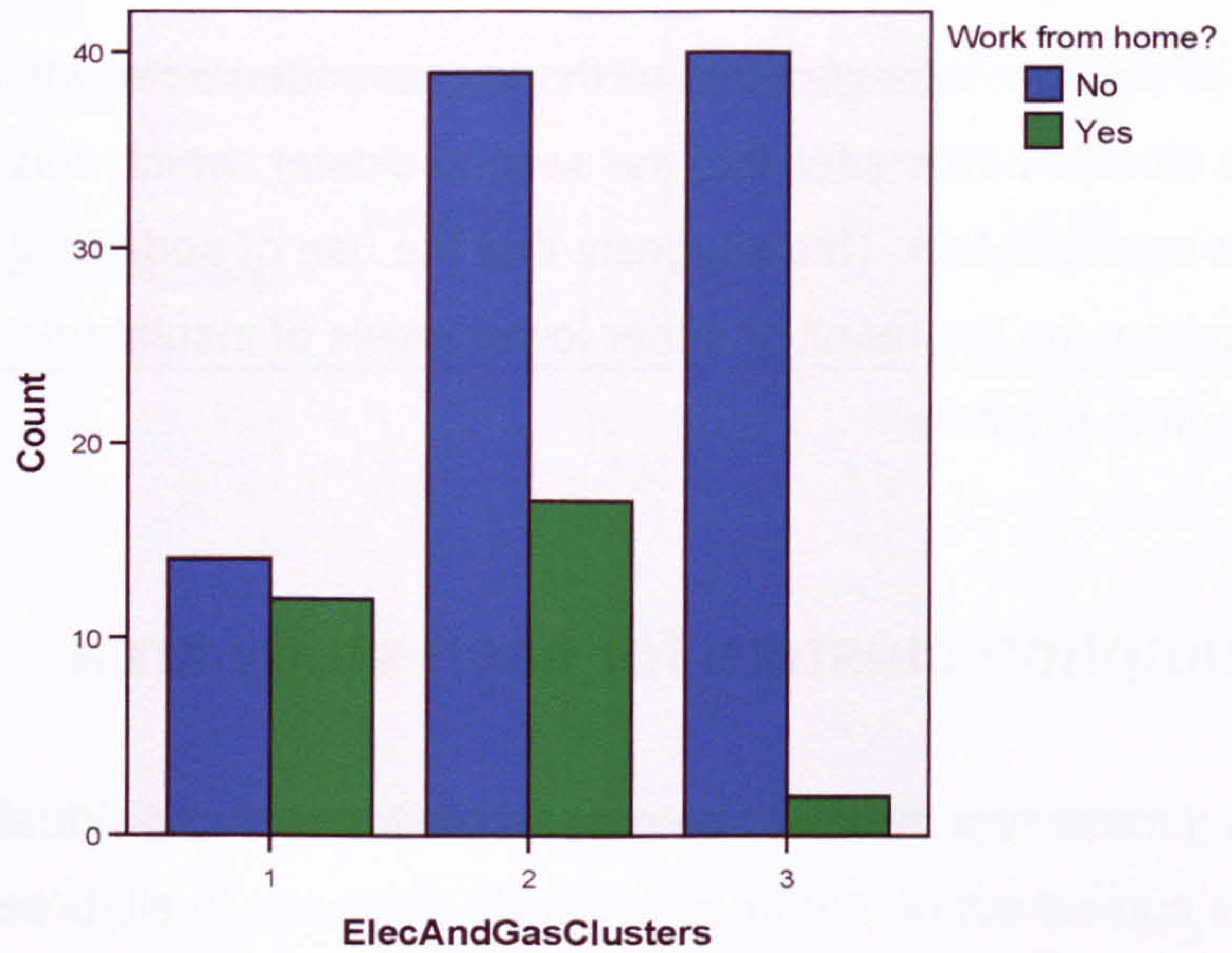


Figure 6.12. Composition by homeworking of the clusters for energy consumption in the combined dataset

Table 6.8. Correlation statistics for the energy consumption clusters in the combined dataset with homeworking

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Interval by Interval	Pearson's R	-.358	.075	-4.229	.000(c)
Ordinal by Ordinal	Spearman Correlation	-.360	.073	-4.265	.000(c)
N of Valid Cases		124			

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

Some evidence of relationships with the clusters was found for wall insulation (-0.197, approx. sig. 0.039) thermostats (-0.194, approx. sig. 0.031) numbers of portable elec heaters in use (-0.164, approx. sig. 0.069) washing machine ownership (-0.172, approx. sig. 0.056) full meals cooked per week (-0.203, approx. sig. 0.026) baths per week (-0.200, approx. sig. 0.049) and digiboxes in use (-0.197, approx. sig. 0.040). As for the variables mentioned previously using these as clustering variables did not result in the reproduction of the distinct clusters of energy consumers. These variables were not analysed further at this stage but were noted for use in the more detailed analyses to follow.

The most notable of these results was that all those respondents reporting the use of 2 or 3 portable electric heaters fell into the second cluster, which was determined by higher gas consumption. This suggests that the use of additional heaters in these dwellings may be the result of either lower levels of insulation and/or inefficient main heating systems.

6.6. Energy consumption clusters for each study area

In order to assess if these results would be repeatable for each individual study area clustering was carried out on the three separate datasets. In all three cases two clusters representing distinct groups of higher and lower energy consumers were produced.

For the Leicester dwellings the clusters consisted of a large group (73.7%) of lower energy consumers and a smaller group of higher energy consumers (Tables 6.9 and 6.10). The distinction was more apparent for gas consumption, which was the higher ranked determining variable, than electricity consumption (Figures 6.13 and 6.14).

Table 6.9. Cluster profiles for energy consumption in the Leicester terraces

		ElecTot		GasTot	
		Mean	Std. Deviation	Mean	Std. Deviation
Cluster	1	4925.3800	1325.63950	41307.9000	8776.31724
	2	2941.8750	1745.64881	15473.4643	6327.36923
	Combined	3463.8500	1853.28215	22272.0000	13448.59310

Table 6.10. Cluster distribution for the Leicester terraces

		N	% of Combined	% of Total
Cluster	1	10	26.3%	18.9%
	2	28	73.7%	52.8%
	Combined	38	100.0%	71.7%
Excluded Cases		15		28.3%
Total		53		100.0%

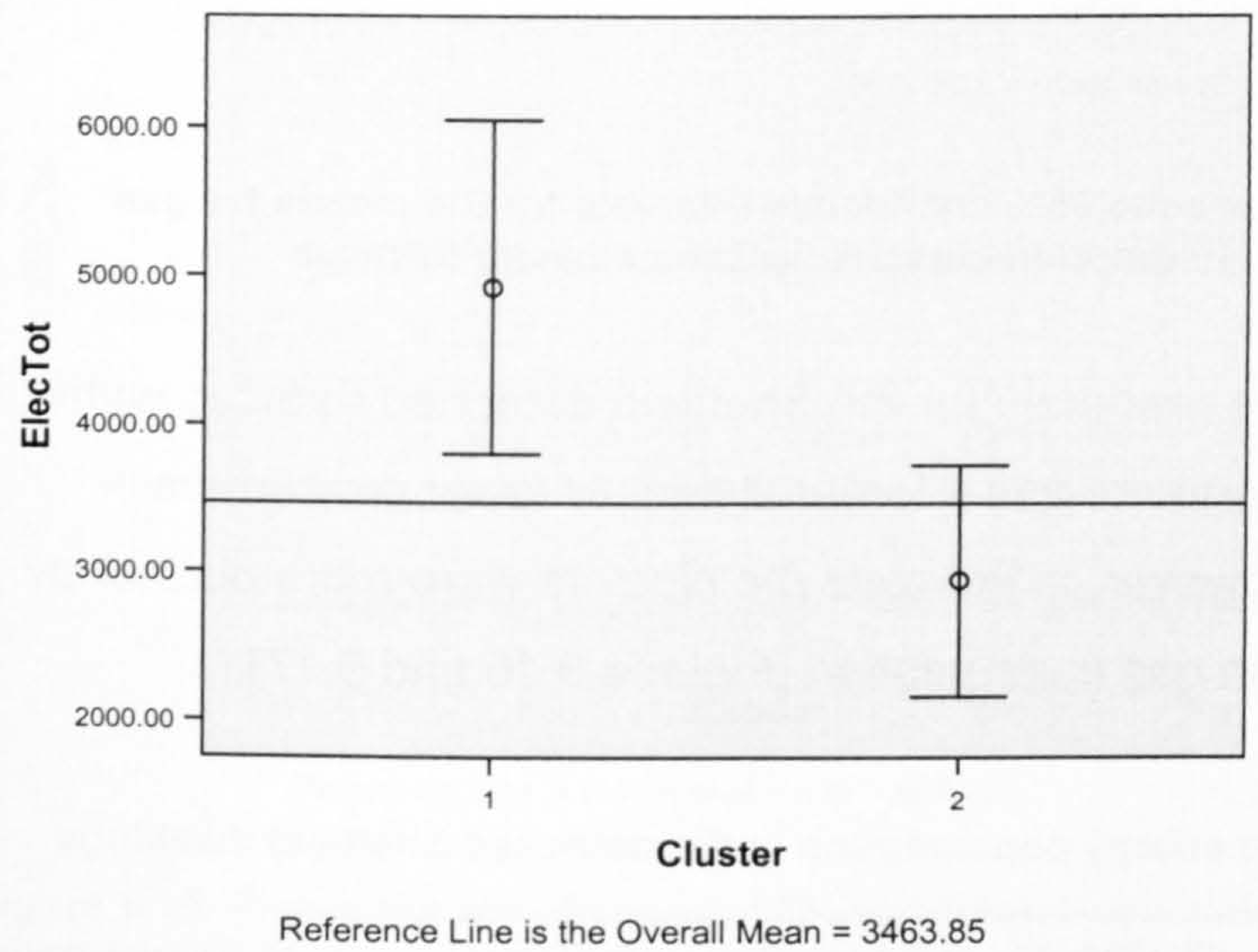


Figure 6.13. Plot of the simultaneous 95% confidence intervals for the means for electricity consumption for the energy consumption clusters for the Leicester terraces

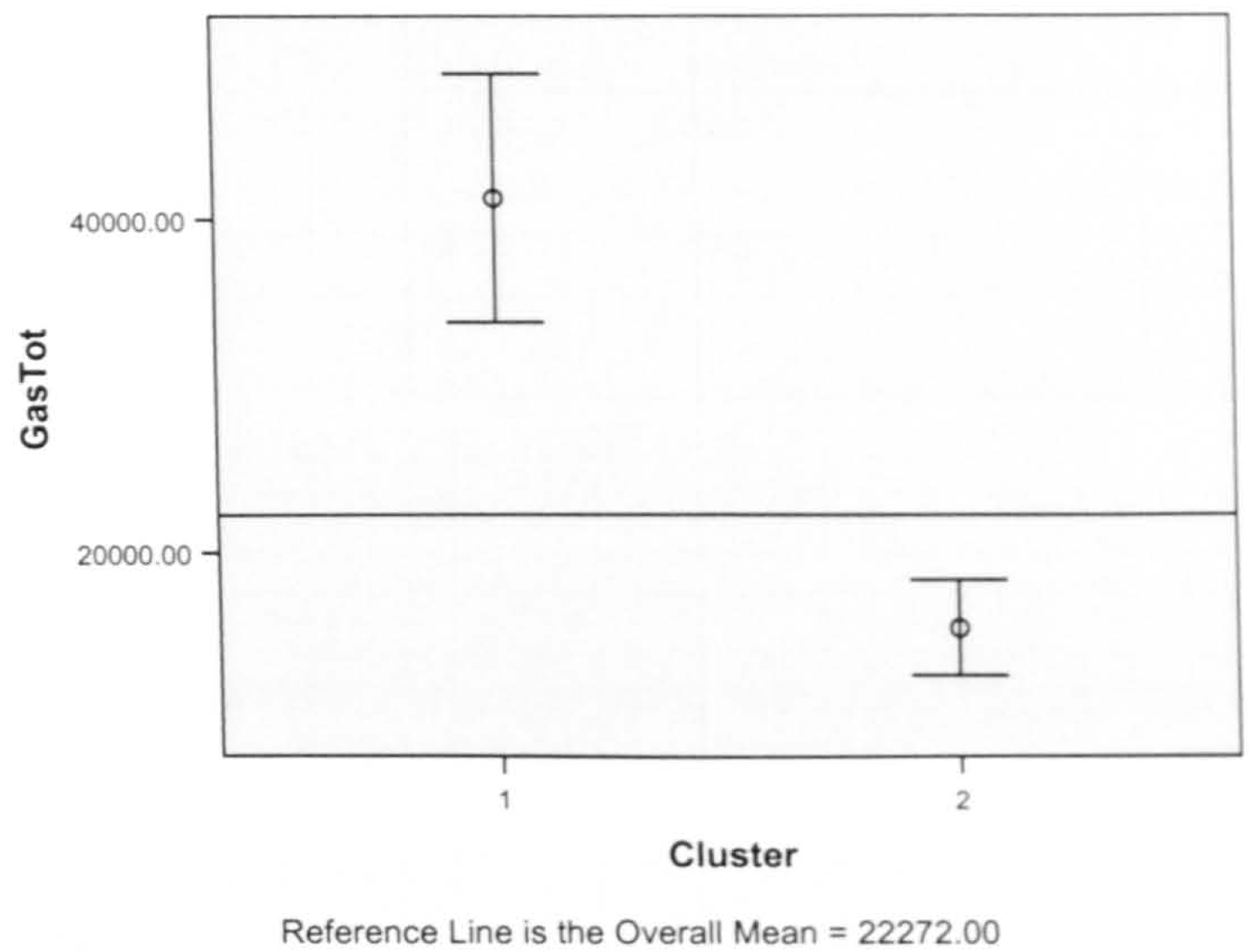


Figure 6.14. Plot of the simultaneous 95% confidence intervals for the means for gas consumption for the energy consumption clusters for the Leicester terraces

Similar clusters were produced for the Sheffield detached dataset, with a small cluster of higher consumers and a larger cluster of lower consumers (Tables 6.11 and 6.12). However, in the case the clusters were more distinct by electricity consumption than gas consumption (Figures 6.16 and 6.17).

Table 6.11. Cluster profiles for energy consumption in the detached Sheffield dwellings

		ElecTot		GasTot	
		Mean	Std. Deviation	Mean	Std. Deviation
Cluster	1	8025.5308	2816.66967	43192.2308	15666.50109
	2	3964.8000	1450.51383	28929.8148	5092.81895
	Combined	5284.5375	2748.43989	33565.1000	11771.98747

Table 6.12. Cluster distribution for the detached Sheffield dwellings

		N	% of Combined	% of Total
Cluster	1	13	32.5%	27.1%
	2	27	67.5%	56.3%
	Combined	40	100.0%	83.3%
Excluded Cases		8		16.7%
Total		48		100.0%

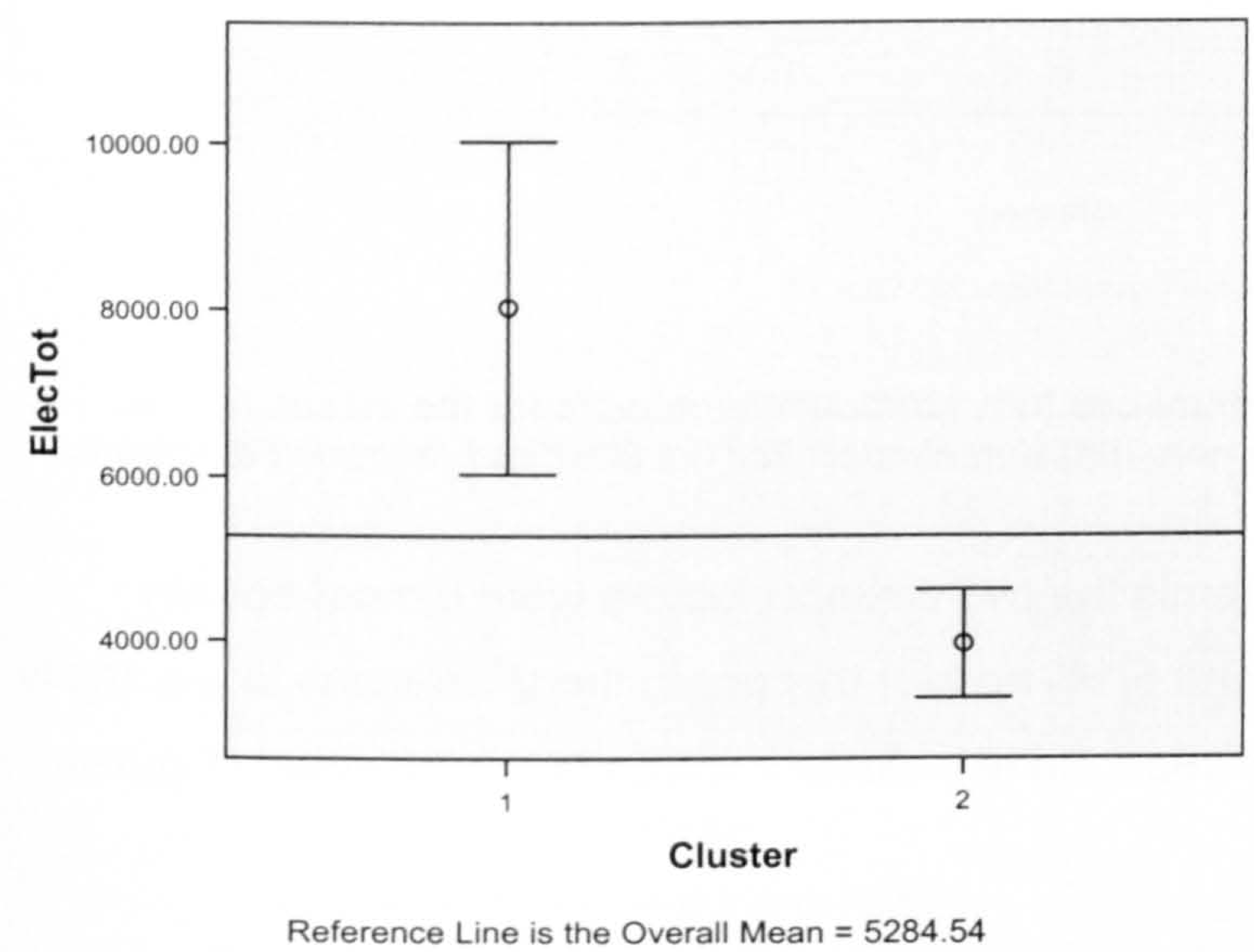


Figure 6.15. Plot of the simultaneous 95% confidence intervals for the means for electricity consumption for the energy consumption clusters for the Sheffield detached dwellings

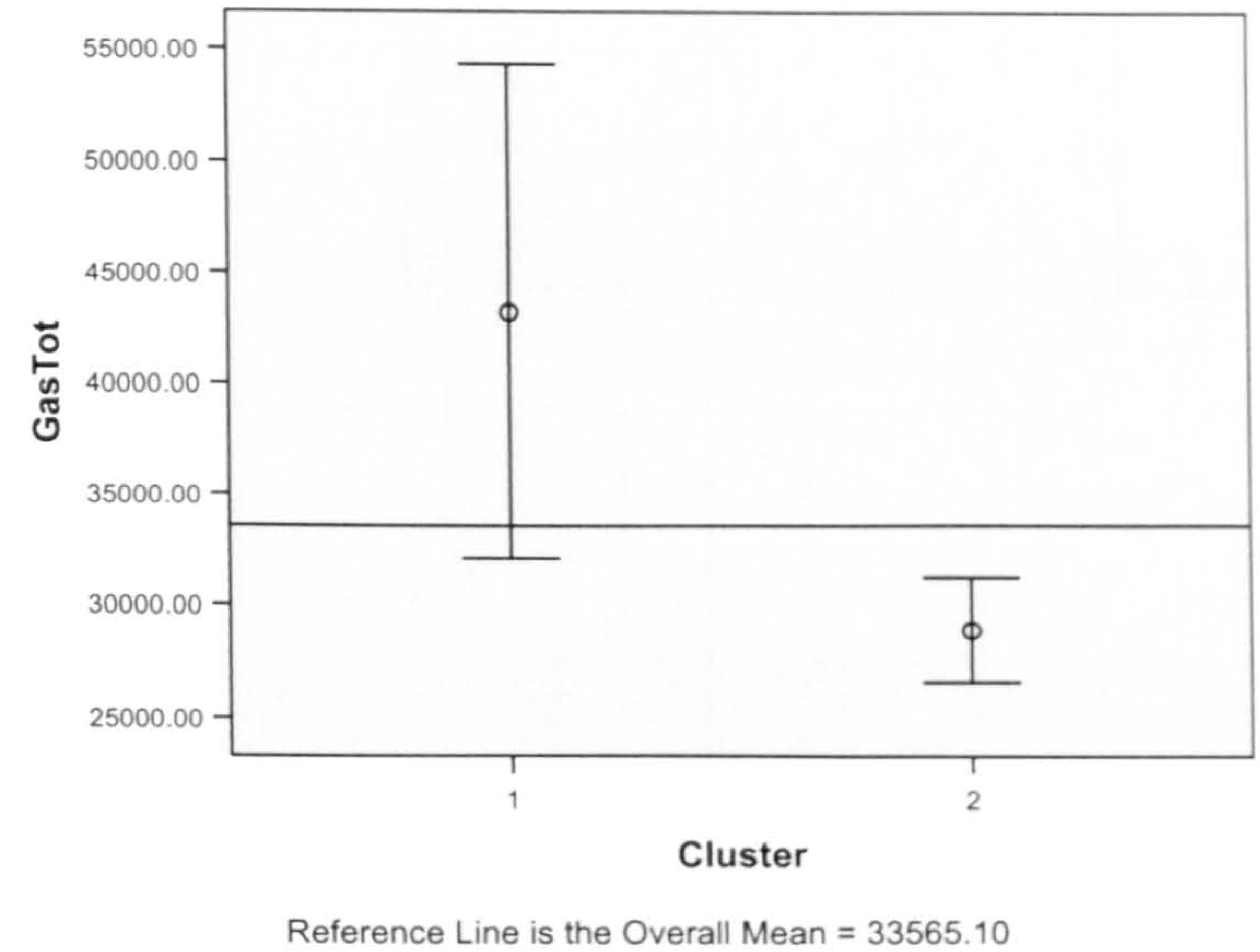


Figure 6.16. Plot of the simultaneous 95% confidence intervals for the means for gas consumption for the energy consumption clusters for the Sheffield detached dwellings

For the Sheffield semis the two distinct clusters were almost equally distributed (Tables 6.13 and 6.14) and for this group the differences in electricity and gas consumption between the two clusters were also more equal (Figures 6.17 and 6.18).

Table 6.13. Cluster profiles for energy consumption in the Sheffield semis

		ElecTot		GasTot	
		Mean	Std. Deviation	Mean	Std. Deviation
Cluster	1	2523.5167	926.84839	17906.8750	6847.77307
	2	5559.9955	1922.80858	30614.4091	7269.28481
	Combined	3975.7457	2125.14602	23984.3913	9477.14718

Table 6.14. Cluster distribution for the Sheffield semis

		N	% of Combined	% of Total
Cluster	1	24	52.2%	44.4%
	2	22	47.8%	40.7%
	Combined	46	100.0%	85.2%
Excluded Cases		8		14.8%
Total		54		100.0%

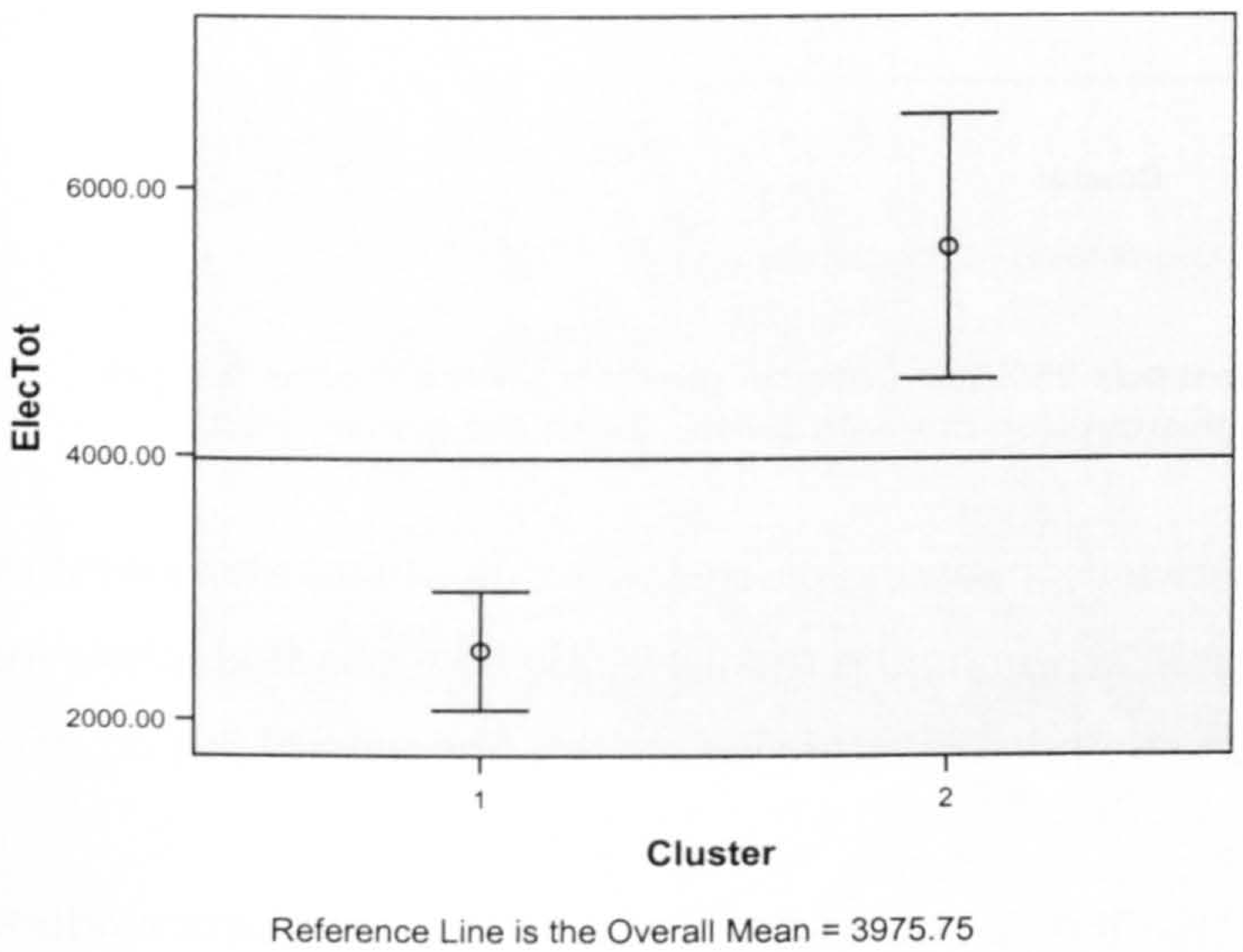


Figure 6.17. Plot of the simultaneous 95% confidence intervals for the means for electricity consumption for the energy consumption clusters for the Sheffield semis

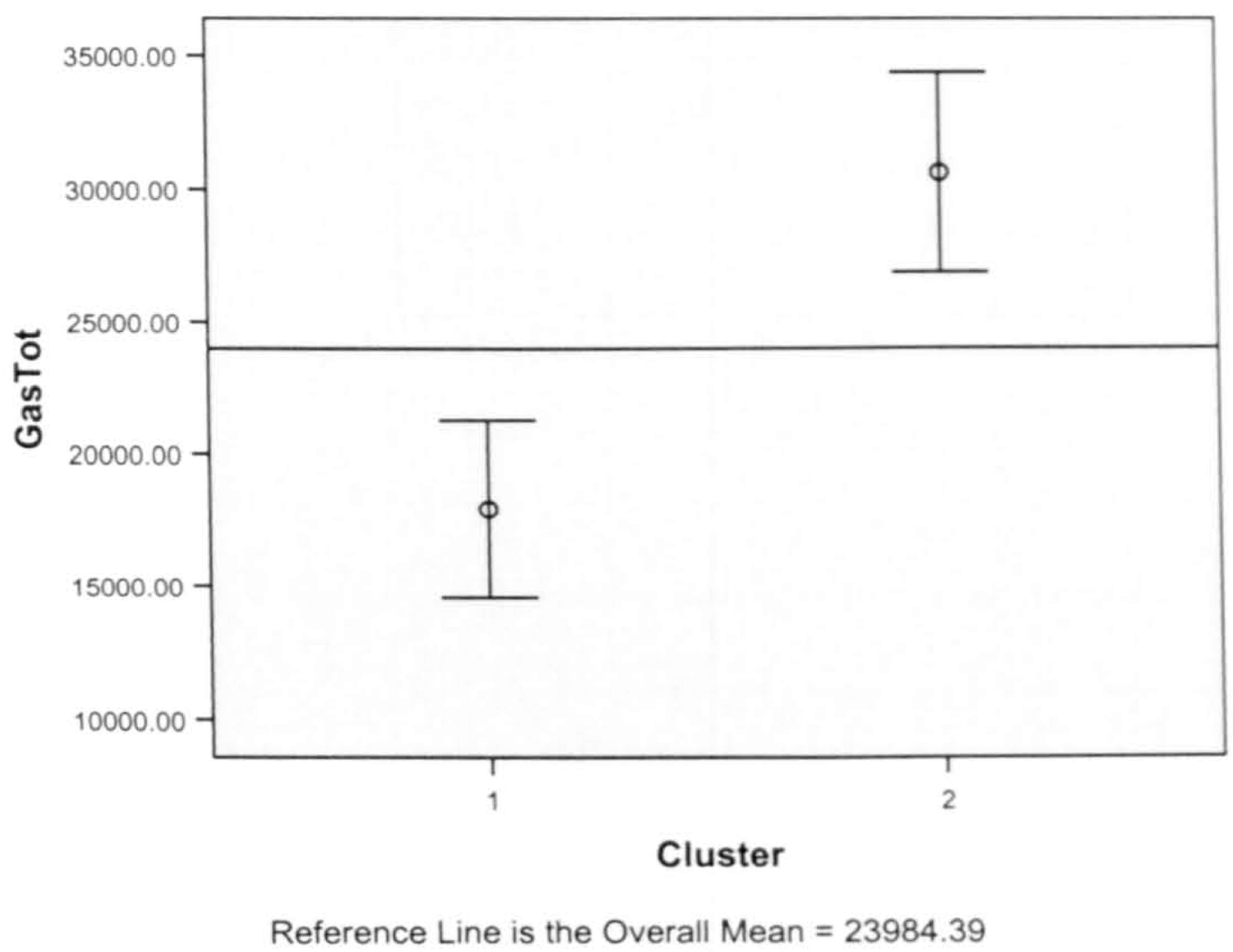


Figure 6.18. Plot of the simultaneous 95% confidence intervals for the means for gas consumption for the energy consumption clusters for the Sheffield semis

For this dataset the lower consuming cluster was output first and therefore it should be noted that when interpreting the results in the sections that follow the direction of the correlations with these clusters will be the opposite of the other two samples.

These results show that the distinct clusters of energy consumers evident in the combined dataset could also be found in the individual study areas. Using MapInfo these high and low consuming dwellings were mapped on the study areas (Figures 6.19 and 6.20). The exact locations of the dwellings have been obscured to comply with the Data Protection Act.

Figure 6.19. Map of Clarendon Park, Leicester, showing clusters for higher (red) and lower (green) energy consuming dwellings

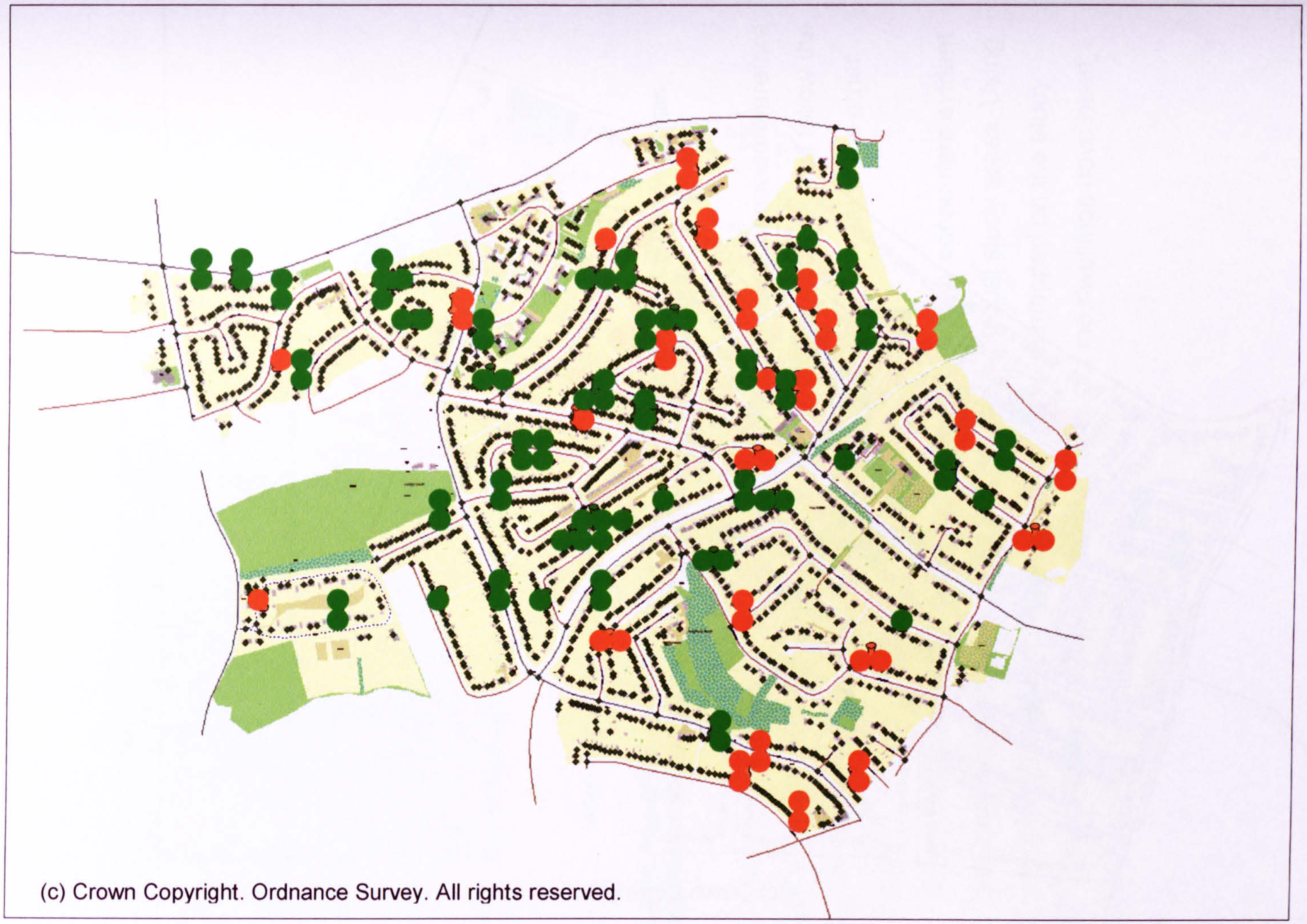


Figure 6.19. Map of Fulwood, Sheffield, showing clusters for higher (red) and lower (green) energy consuming dwellings

For the Clarendon Park, Leicester, study area the distribution of the dwellings falling into the higher and lower consuming clusters shows all but three of the dwellings in the higher consuming cluster are larger terraces in the east of the study area. Of the remaining three, two are end-terraces. Only one of the larger terraces is grouped into the lower consuming cluster.

For the Fulwood, Sheffield, study area there appears to be no physical distinction between the dwellings in the higher and lower consuming clusters. Both clusters contain detached and semi-detached dwellings and no geographical grouping is evident.

The next step was to ascertain whether or not these clusters could also be differentiated by the same variables.

6.7. Composition of the energy consumption clusters for the study areas

TFA

As for the combined dataset TFA was grouped into five bands each containing 20% of the records (approximately 10 records in each). The Spearman correlations and approximated significance values for these correlations are given in Table 6.15.

Table 6.15. Correlations of clusters for the three study areas with 20% bands for TFA

	Spearman correlation	Approx. Sig.
Leicester	-0.557	0.000
Sheffield Detached	-0.238	0.138
Sheffield Semis	0.089*	0.557
*Correlation is positive as the lower consuming cluster was output first		

These results are surprising as although correlation for the Leicester terraces is strong and significant this is not true for either of the Sheffield samples, in particular the semis. However, this may be explained by the fact that there are only one third of the records in the bands for TFA than for those produced from the combined dataset, and therefore the average value for TFA within each band is more open to being leveraged by values at the upper and lower ends of the scale. Furthermore, subsequent analyses of the data for the semis (chapters 7 and 8) found much weaker relationships between energy consumption and almost all the variables in the dataset.

Occupancy

As for the combined dataset strong correlations were found with occupancy for the clusters for all three study areas. The Spearman correlations and approximated significance values for these correlations are given in Table 6.16.

Table 6.16. Correlations of clusters for the three study areas with occupancy

	Spearman correlation	Approx. Sig.
Leicester	-0.569	0.000
Sheffield Detached	-0.468	0.002
Sheffield Semis	0.279*	0.061
*Correlation is positive as the lower consuming cluster was output first		

The statistics show the strongest correlation with occupancy was found for the Leicester terraces. This may be because Leicester respondents reported the greatest range of occupancy (1-7) whilst respondents in both Sheffield samples reported a range of 1-4. The weakest correlation is for the Sheffield semis (which fails the significance test at p=0.05).

Dwelling age

As expected no correlation was found with dwelling age for the Leicester terraces. This was unsurprising because the built form type in the area is highly homogeneous and it is reasonable to expect an element of error in respondents' reporting which of the two age brackets (pre-1900 or 1900-1929) their dwellings fell into. However, as shown in Table 6.17 correlations were found for both Sheffield samples. This was strongest for the detached dwellings which also had the greatest range of dwelling ages (pre-1900 to 1982-89). As for occupancy a weaker and less significant correlation was found with dwelling age for the Sheffield semis.

Table 6.17. Correlations of clusters for the three study areas with dwelling age

	Spearman correlation	Approx. Sig.
Leicester	-0.103	0.558
Sheffield Detached	0.325	0.041
Sheffield Semis	-0.269	0.070
*Correlation is negative as the lower consuming cluster was output first		

Both Sheffield samples were predominantly composed of dwellings in the middle age brackets. For the detached the predominant groups were in the 1950-65 and 1966-76 brackets (30% and 42.5% respectively) whilst the semis sample was predominantly composed of dwellings in the 1950-65 bracket (58.7%). In both groups there was clear evidence of dwellings constructed before 1950 falling into the higher consuming cluster and those constructed after 1976 falling into the lower consuming cluster. The unequal distributions can be expected to have influenced the strength of the correlations and therefore this is not sufficient evidence to reject the value of dwelling age as an explanatory variable.

Rooms and bedrooms

The strongest and most consistent correlations between the clusters and the variables in the datasets were found with the numbers of rooms and bedrooms. The summary statistics for these correlations are given in Table 6.18, which shows that, as was found for the combined dataset, the number of bedrooms was the more powerful explanatory variable for all three samples.

Table 6.18. Correlations of clusters for the three study areas with the numbers of rooms and bedrooms

	Number of Rooms .		Number of Bedrooms	
	Spearman correlation	Approx. Sig.	Spearman correlation	Approx. Sig.
Leicester	-0.545	0.000	-0.626	0.000
Sheffield Detached	-0.303	0.061	-0.345	0.032
Sheffield Semis	0.298*	0.044	0.552*	0.000
*Correlation is positive as lower consuming cluster was output first				

This table contains several important results. The correlations with the numbers of bedrooms are stronger and more significant than with the numbers of rooms, and in the case of the detached Sheffield sample the latter fails the significance test at p=0.05. The most notable difference in correlation is found for the Sheffield semis. The range in the number of bedrooms was smallest for this group (2-5, as opposed to 2-6 for the terraces and detached samples) whilst the range for the number of rooms was lowest for the terraces (5-11) slightly higher for the semis (6-13) and highest for the detached dwellings (4-15).

Without the local knowledge that could be brought to bear on the results for the Leicester terraces it is difficult to explain the differences found for the correlations for the dwellings in the Sheffield samples.

These results are discussed in more detail in section 7.4.

Homeworking

Homeworking was the only other variable found to correlate consistently with the consumption clusters for all three study areas, although the correlations were weaker and less significant for the variables reported thus far. The summary statistics for these correlations are given in Table 6.19 which also includes the statistics for the correlations between homeworking and the consumption data split into five bands (as was done with TFA).

Table 6.19. Correlations for homeworking with the clusters for the three study areas and the banded consumption data

		Spearman correlation	Approx. Sig.
Leicester	Energy consumption clusters	-0.365	0.024
	Banded electricity data	0.360	0.009
	Banded gas data	0.456	0.004
Sheffield detached	Energy consumption clusters	-0.290	0.070
	Banded electricity data	0.302	0.042
	Banded gas data	0.244	0.119
Sheffield semis	Energy consumption clusters	0.250*	0.094
	Banded electricity data	0.263	0.060
	Banded gas data	0.124	0.240
*Correlation is positive as lower consuming cluster was output first			

In this case the differences between the correlations may be indicative of the proportions of homeworkers in each sample (31.6%, 27.5% and 17.4% for the Leicester, Sheffield detached and Sheffield semis respectively). There is also the limitation that the clusters were only produced using the dwellings for which both electricity and gas consumption records were obtained, thus further reducing the number of records that could be analysed (see the cluster distribution tables).

It is interesting to note that although the correlations with the banded consumption data are reasonably consistent there is no clear evidence that they are stronger for either gas or electricity consumption. Indeed when the consumption data for the combined dataset was banded in the same way the results were remarkably similar (Spearman correlation with electricity consumption 0.279, approximated significance 0.001 and Spearman correlation with gas consumption 0.246, approximated significance 0.005). Therefore these results are additional evidence that homeworking is a useful explanatory variable for differences in both electricity and gas consumption.

Other variables

When other variables identified as potentially significant from the analyses of the combined dataset were correlated with the clusters for the individual study areas none was found to be consistently significant.

For the Leicester terraces correlations were found with dishwasher and PC ownership, as well as some less significant evidence for correlations with freezer and tumble dryer ownership.

No notable correlations were found for the Sheffield detached sample, and for the semis there was a correlation with TV ownership and a less significant correlation with dishwasher ownership. These inconsistencies in the relationships found within each sample may explain why these variables were not found to be significant in determining the consumption clusters discovered in the combined dataset.

6.8. Results of clustering on the combined dataset using the explanatory variables

In order to assess whether or not the variables identified in these analyses were manifestations of real differences in the data or simply artefacts in a small sample a final set of analysis was preformed. The aim here was to establish whether clustering on energy consumption and the variables found to be related to the clusters for the consumption data only could reproduce the two distinct groups of energy consumers. That this also demonstrated the value of cluster analysis for determining and illustrating the existence of distinct groups within a dataset is demonstrated by the tables and figures that follow.

Initially the consumption data was clustered along with occupancy, dwelling age, rooms and bedrooms. This did produce three clusters and although they were not clearly distinct in terms of energy consumption there were clear differences in occupancy and the number of bedrooms, and to a lesser extent age and the number of rooms.

As total floor area is known to have a strong influence on domestic energy consumption this was added to the clustering, but again three clusters emerged that were still not clearly distinct. However, when homeworking was added two clusters were produced that were clearly distinct by energy consumption, TFA, occupancy, rooms and bedrooms, and to a lesser extent dwelling age and homeworking itself. None of the other variables found to be related to the clusters were found to reproduce the two consumption clusters when used in these analyses.

The key outputs for this analysis are given in Tables 6.20 and 6.21 and Figures 6.21 to 6.32, which show that there was a clear distinction between the energy consumption of the dwellings in the two clusters at the 95% confidence level. The clusters were then crosstabulated with built form type to assess whether or its influence became evident after these variables had been accounted for, and as shown in Figure 6.33 there was no evidence for this.

Table 6.20. Cluster profiles for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

			Mean	Std. Deviation
Cluster	1	ElecTot	5456.0118	2480.01493
		GasTot	33988.7255	12335.63811
		TotFloorArea	187.4047	56.57339
		Total Number of Occupants	2.6078	.85037
	2	ElecTot	3264.3743	1761.55672
		GasTot	20727.3143	9040.96877
		TotFloorArea	111.6596	30.05544
		Total Number of Occupants	1.8143	.87299
	Combined	ElecTot	4188.1223	2351.15720
		GasTot	26316.8347	12395.27545
		TotFloorArea	143.5852	57.12792
		Total Number of Occupants	2.1488	.94570

Table 6.21. Cluster distribution for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

		N	% of Combined	% of Total
Cluster	1	51	42.1%	33.1%
	2	70	57.9%	45.5%
	Combined	121	100.0%	78.6%
Excluded Cases		33		21.4%
Total		154		100.0%

The distribution statistics for the two clusters show that there is relatively even division in the records, again this is important as a heavily skewed distribution would be evidence of aberrations in the data that would invalidate the conclusions from crosstabulating these clusters with built form type.

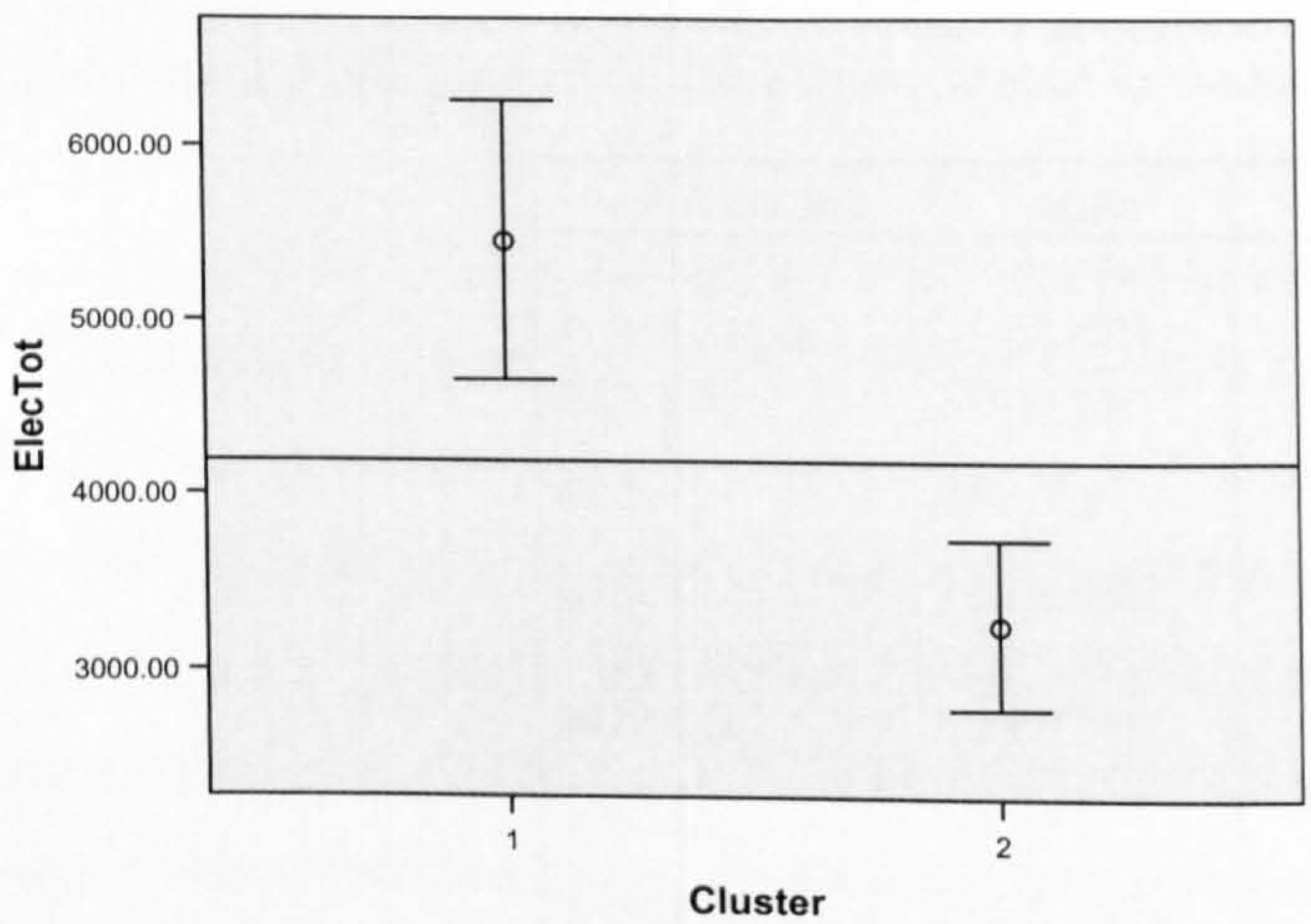


Figure 6.21. Plot of the simultaneous 95% confidence intervals for the means for electricity consumption for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

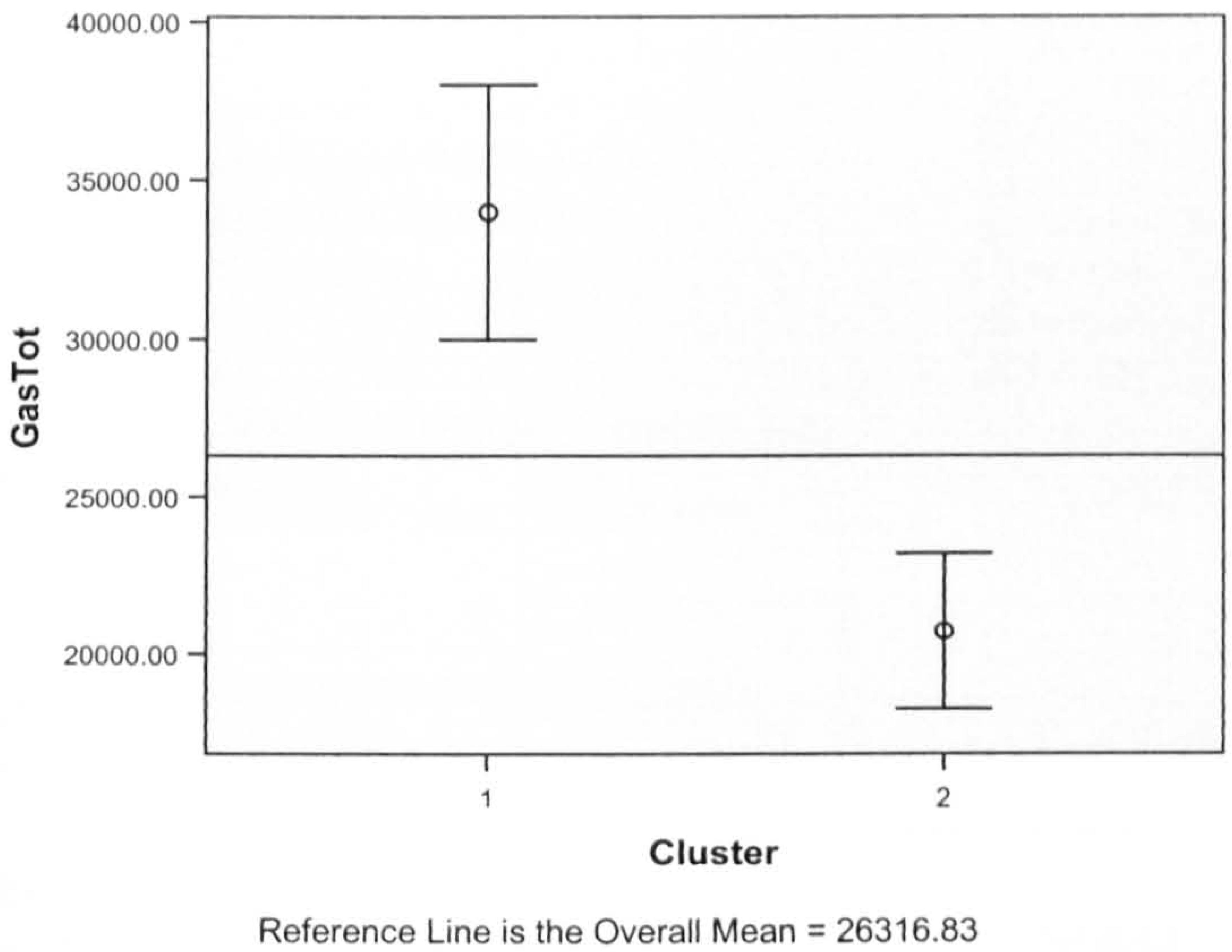


Figure 6.22. Plot of the simultaneous 95% confidence intervals for the means for gas consumption for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

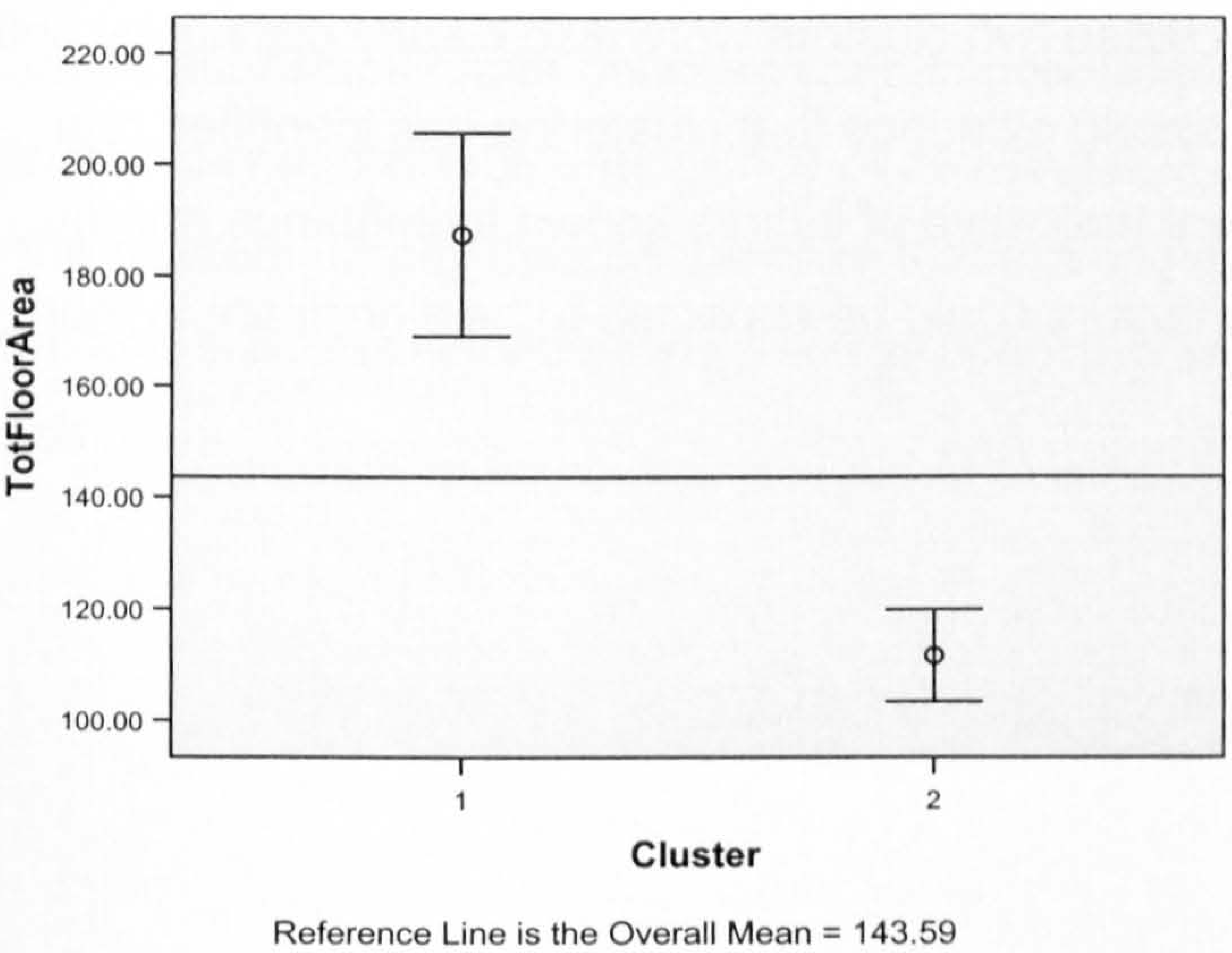


Figure 6.23. Plot of the simultaneous 95% confidence intervals for the means for TFA for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

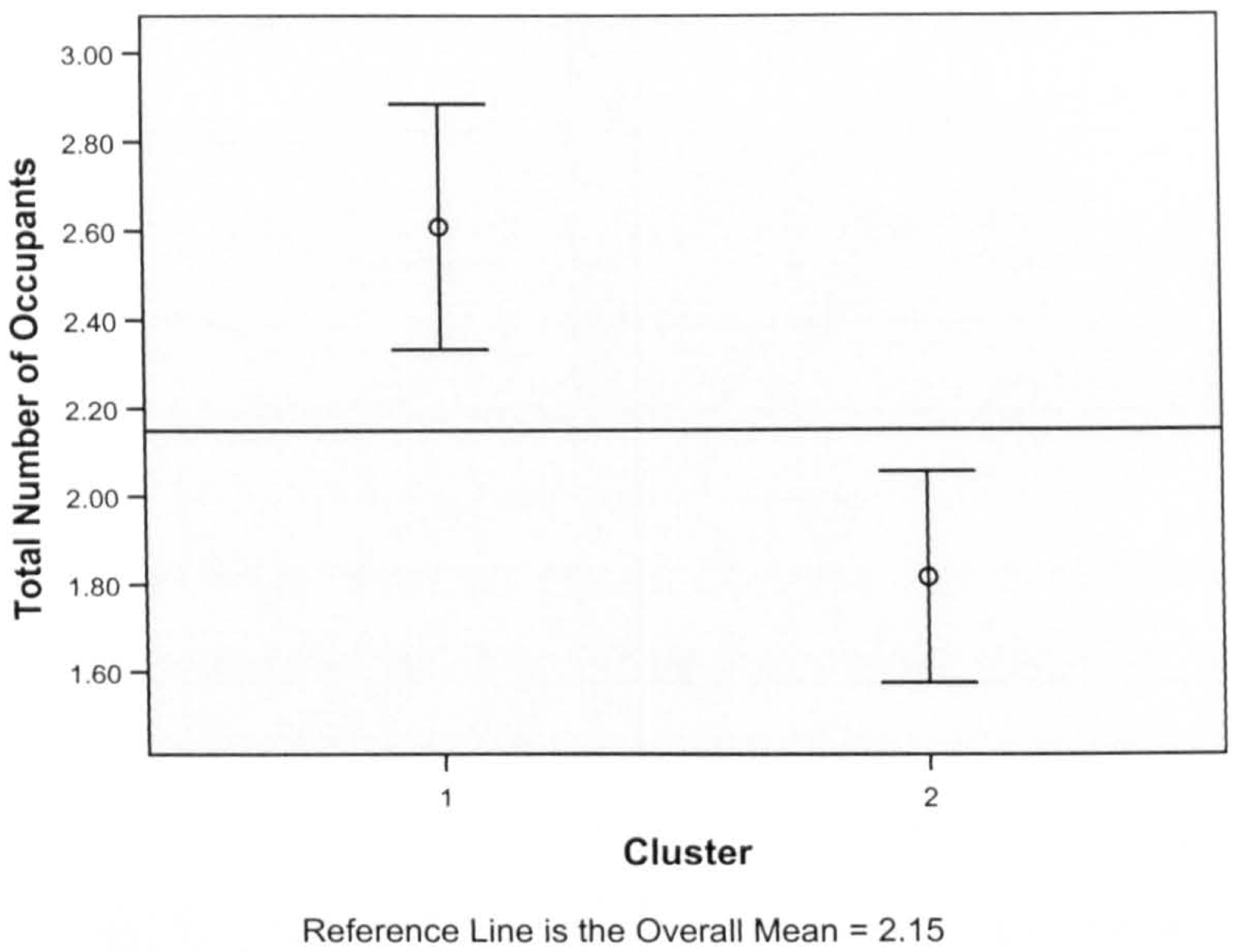


Figure 6.24. Plot of the simultaneous 95% confidence intervals for the means for occupancy for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

Figures 6.23 and 6.24 show that in addition to being distinct by energy consumption the dwellings in these two clusters were also clearly distinct by both TFA and occupancy. This is strong evidence that clustering has identified real groupings in the data that were indicative of factors known to influence energy consumption, and that these factors could be expected to be significant in more detailed analyses.

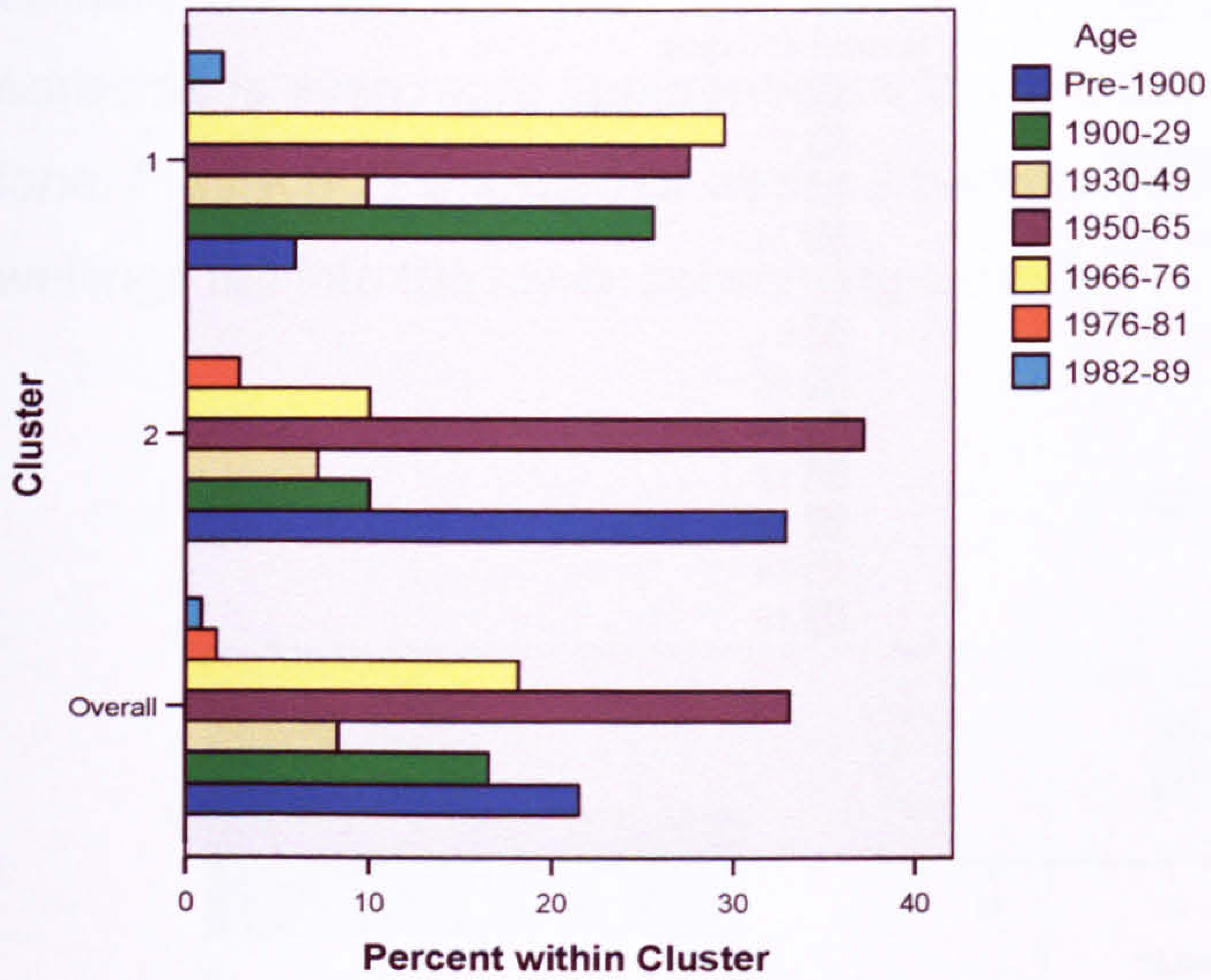


Figure 6.25. Within cluster percentage plot for dwelling age for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

The composition of the clusters by dwelling age (Figure 6.25) shows they are not as distinct in terms of this variable, however as mentioned previously the strong relationships found between consumption and TFA within certain age brackets may explain the emergence of dwelling age as a determining variable for the clusters. It may also be the case that the uneven distribution of dwellings in the age brackets is influencing the significance of dwelling age as a clustering variable.

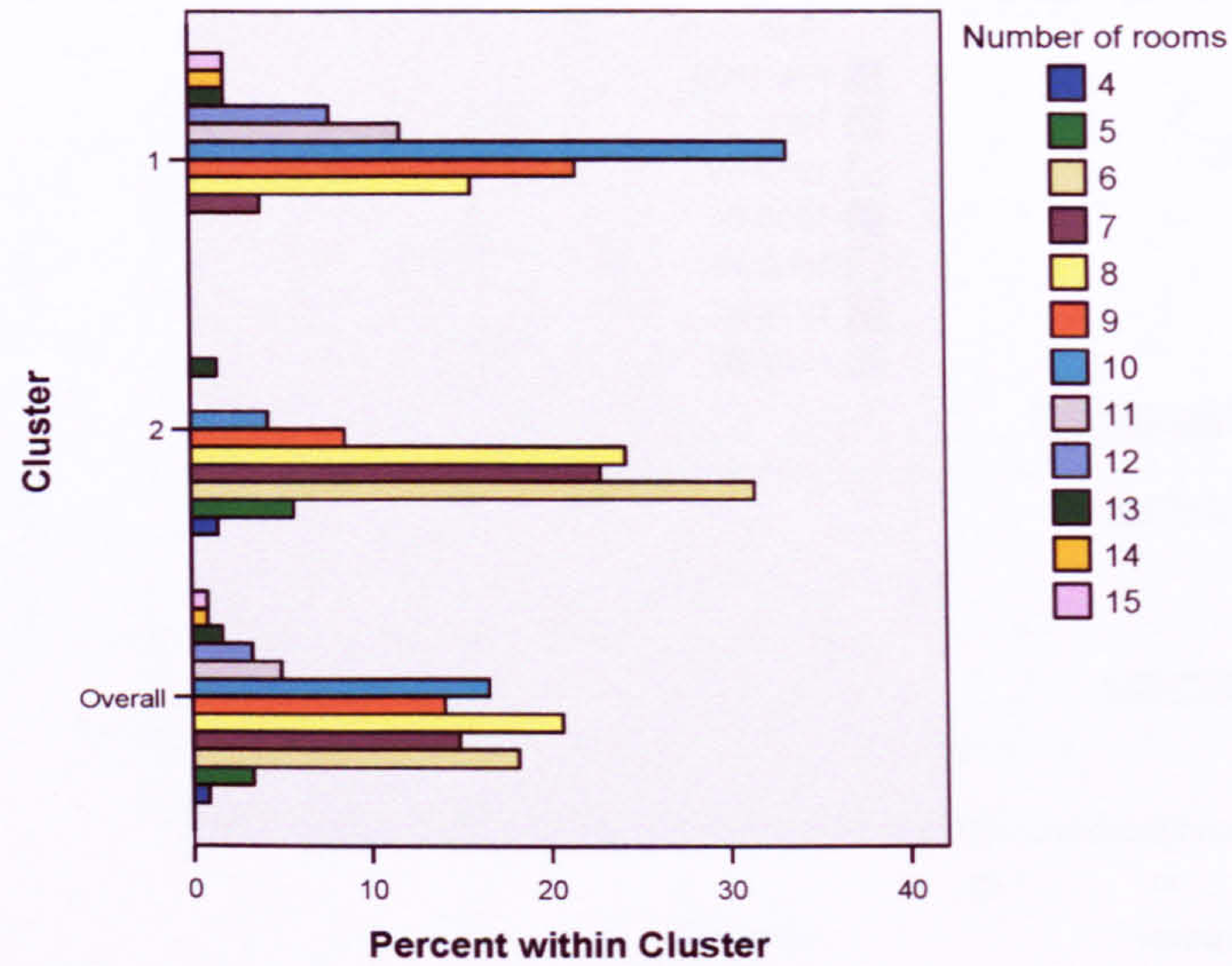


Figure 6.26. Within cluster percentage plot for the number of rooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

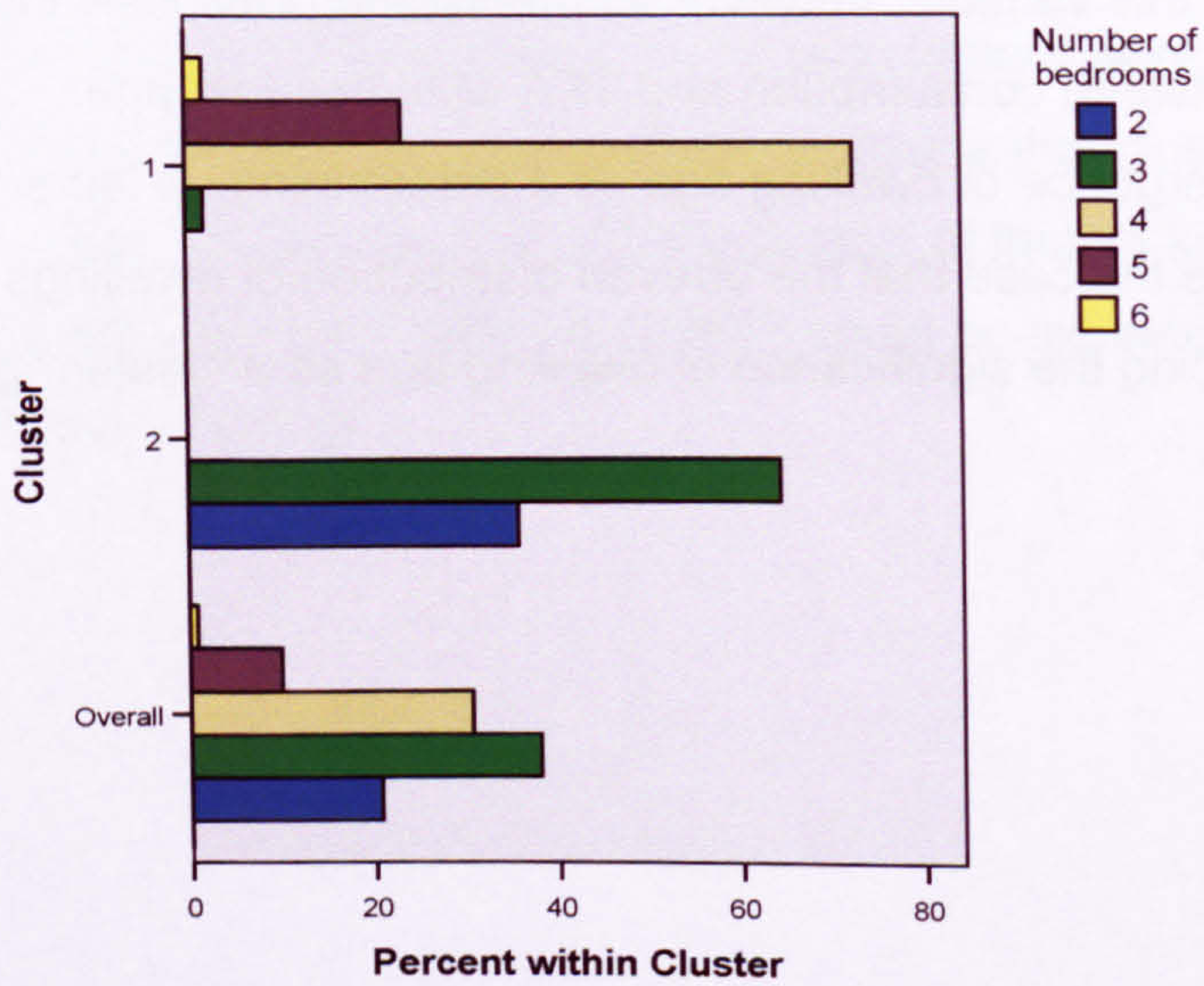


Figure 6.27. Within cluster percentage plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

Again there is a clear indication that the clusters are differentiated by the numbers of rooms and bedrooms, but in this case the stronger association with bedrooms is even more apparent than for the clusters on energy consumption alone. Figure 6.27 shows that all the 2 bedroom and almost all of the 3 bedroom dwellings fall into the lower consuming cluster.

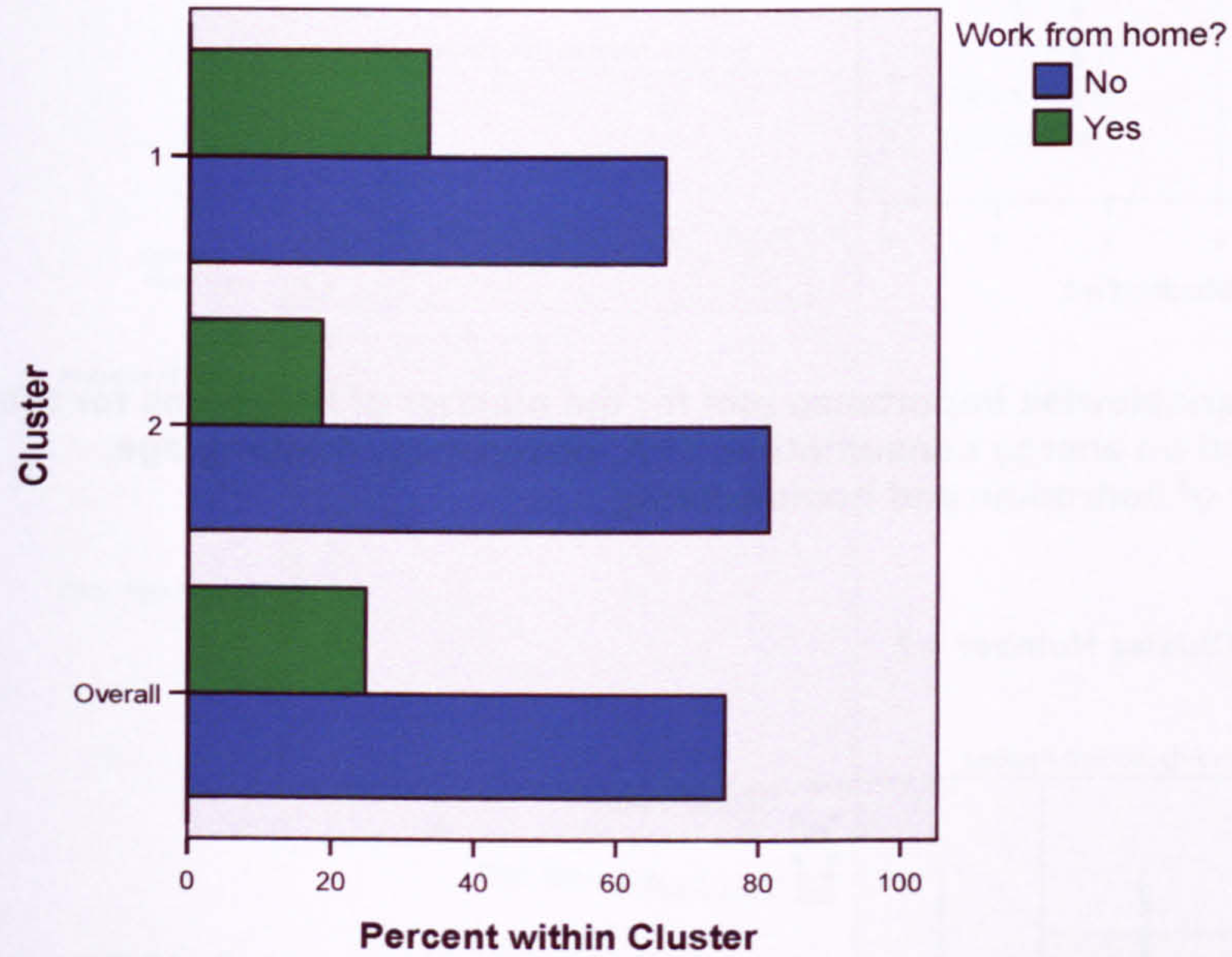


Figure 6.28. Within cluster percentage plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

For homeworking the composition of the clusters again shows a visible tendency towards homeworker households being higher energy consumers.

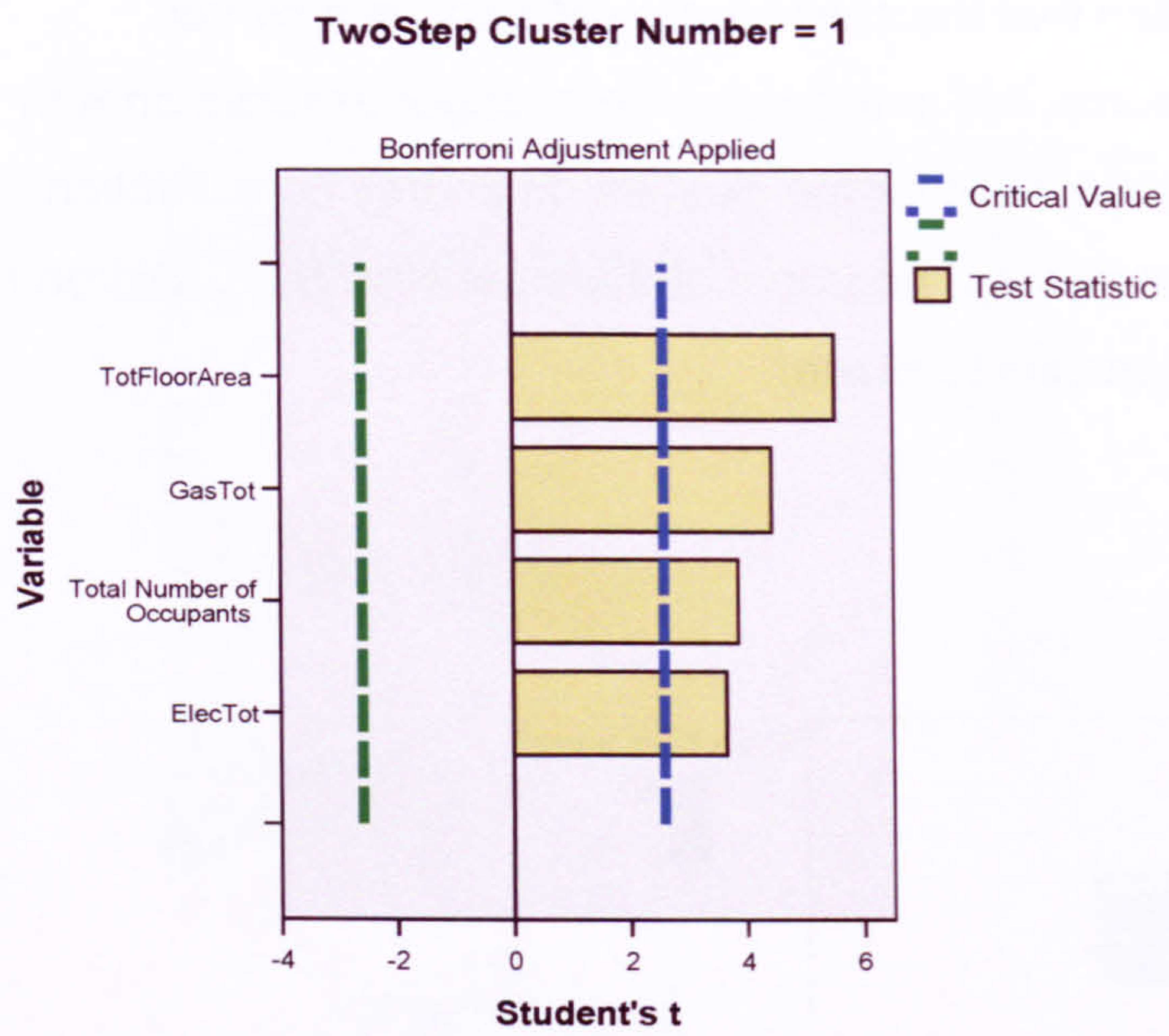


Figure 6.29. Continuous variablewise importance plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

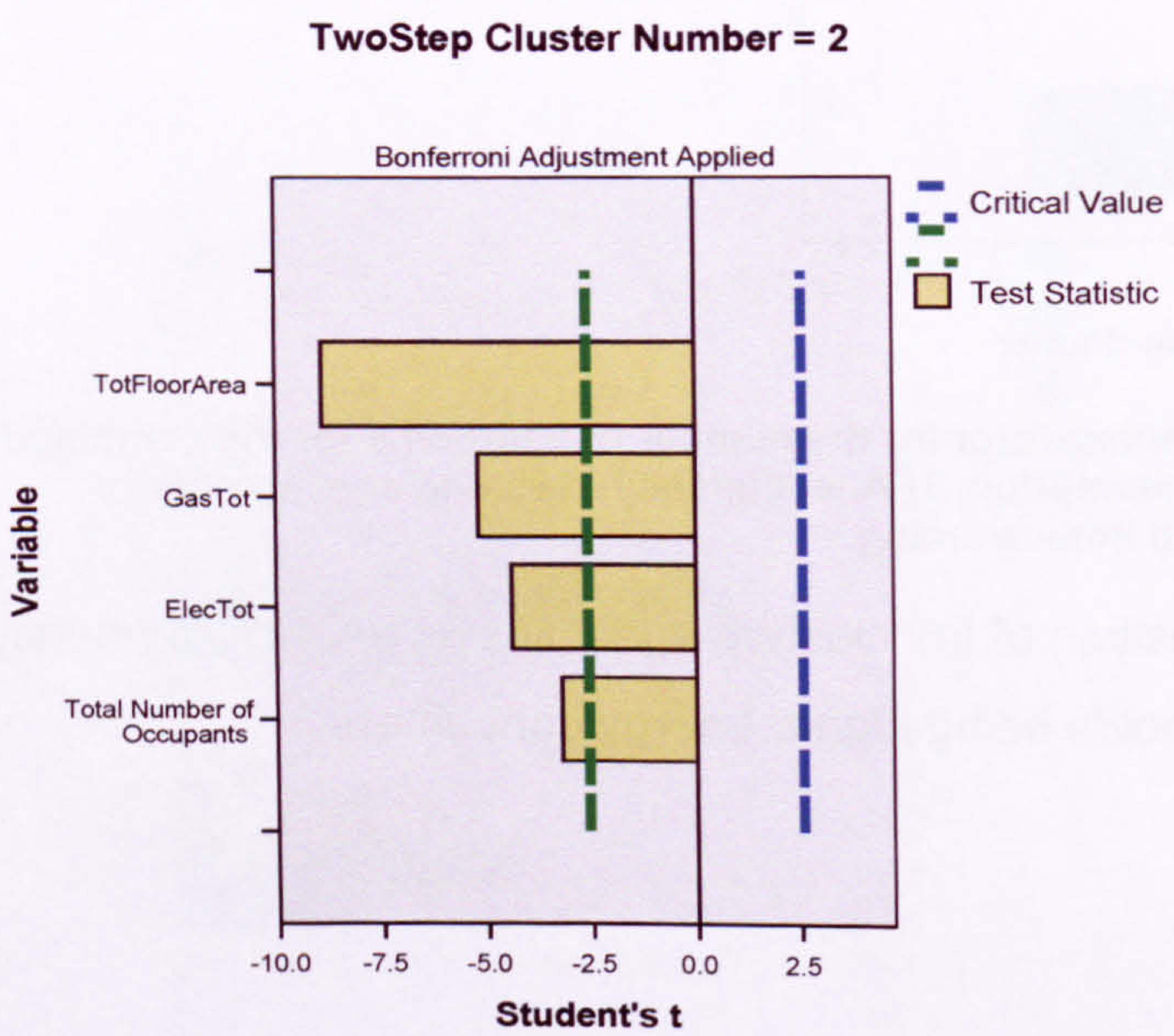


Figure 6.30. Continuous variablewise importance plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

The continuous variablewise importance plots show that all the variables exceeded the critical value for determining the clusters, but in both cases TFA was the highest ranked variable. This is consistent with knowledge of the level of its impact on dwelling energy consumption. Gas consumption is ranked second for both clusters, which is consistent with this result as almost all the dwellings in the dataset were heated by gas fuelled radiator systems these variables should be closely related.

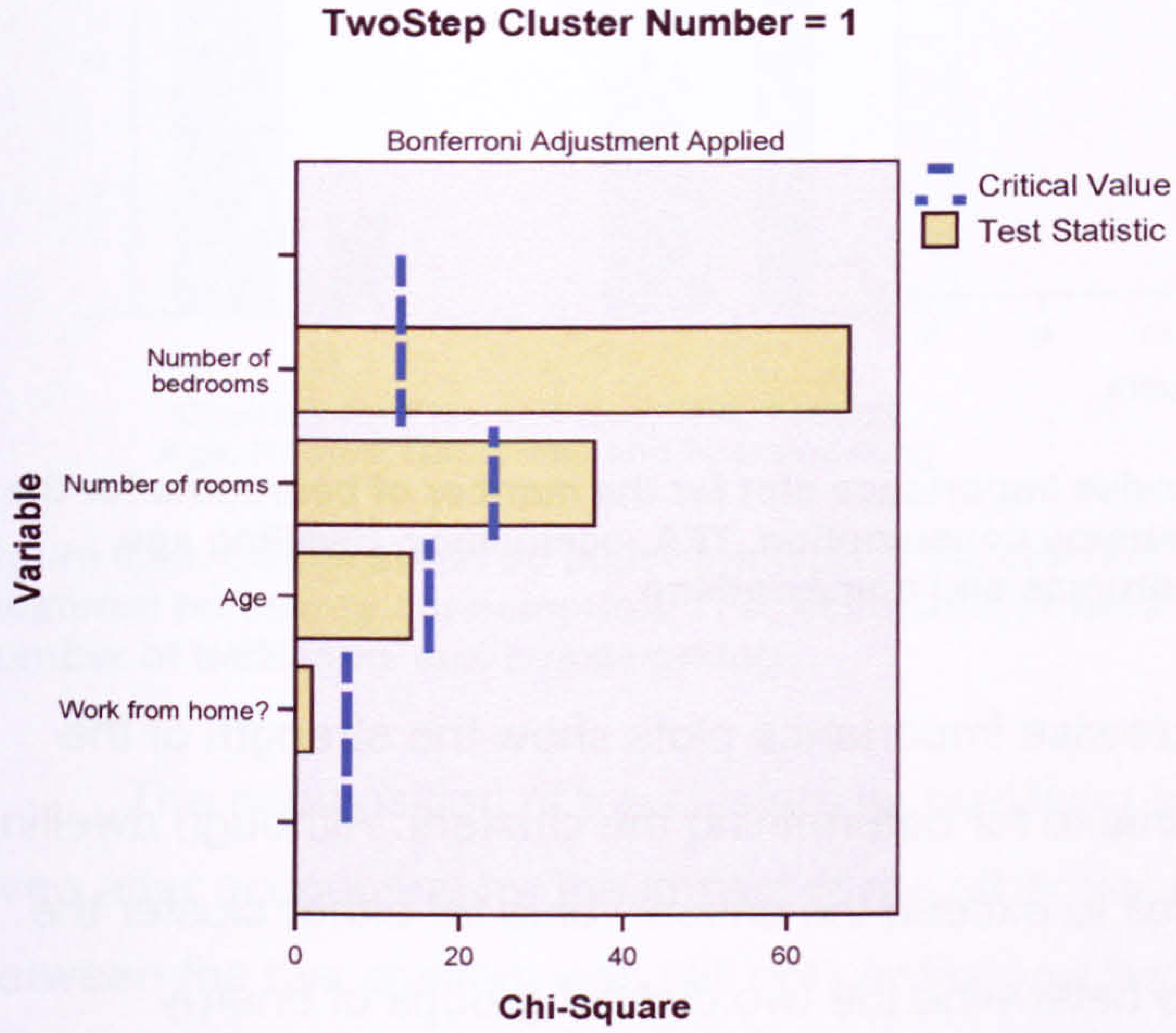


Figure 6.31. Categorical variablewise importance plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

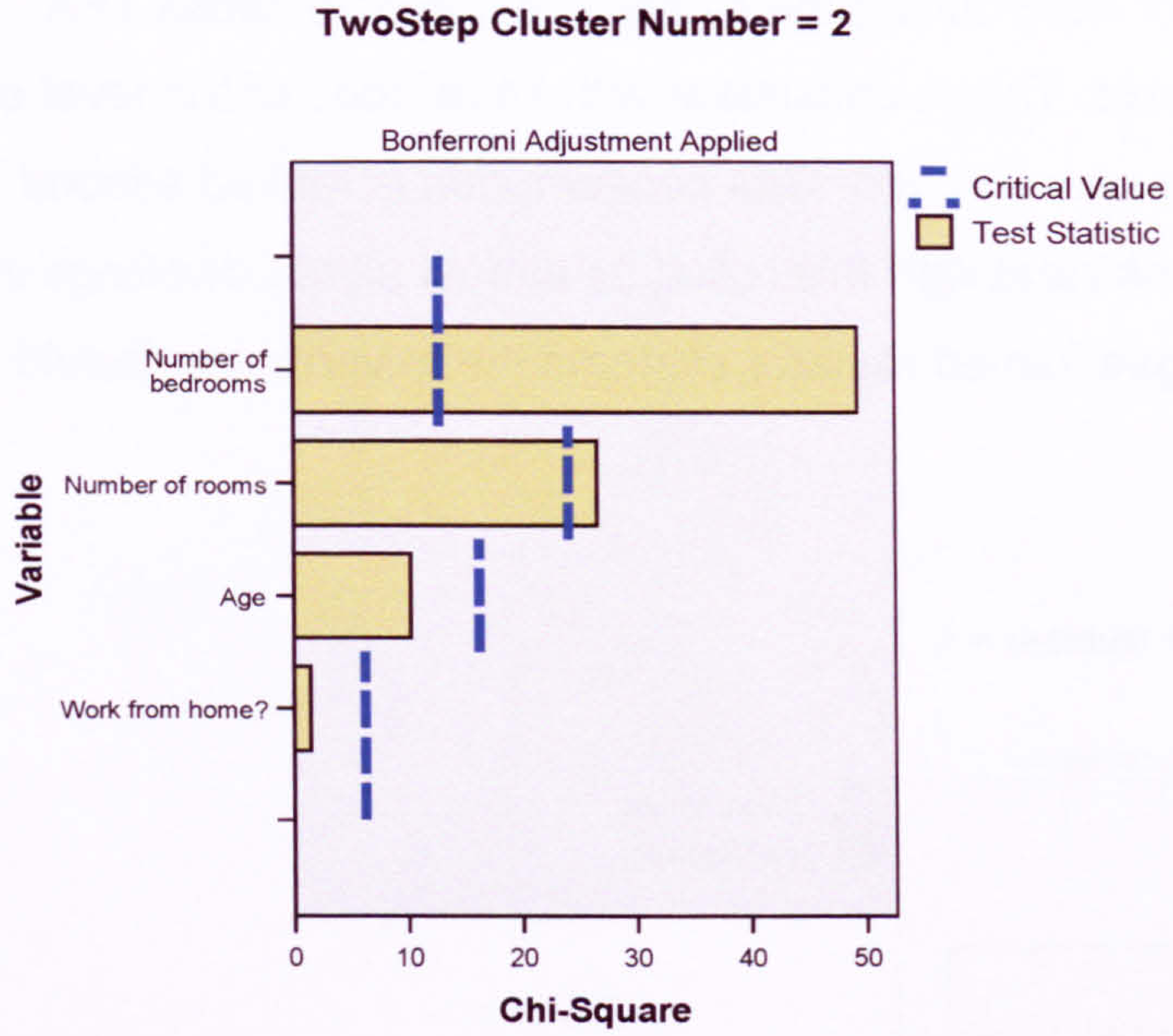


Figure 6.32. Categorical variablewise importance plot for the number of bedrooms for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

The categorical variablewise importance plots show the strength of the number of bedrooms as a variable for determining the clusters. Although dwelling age and homeworking both fail to exceed the critical value for either cluster the fact that both were needed to determine the two distinct groups of energy consumers suggests that they should not be dismissed as explanatory variables.

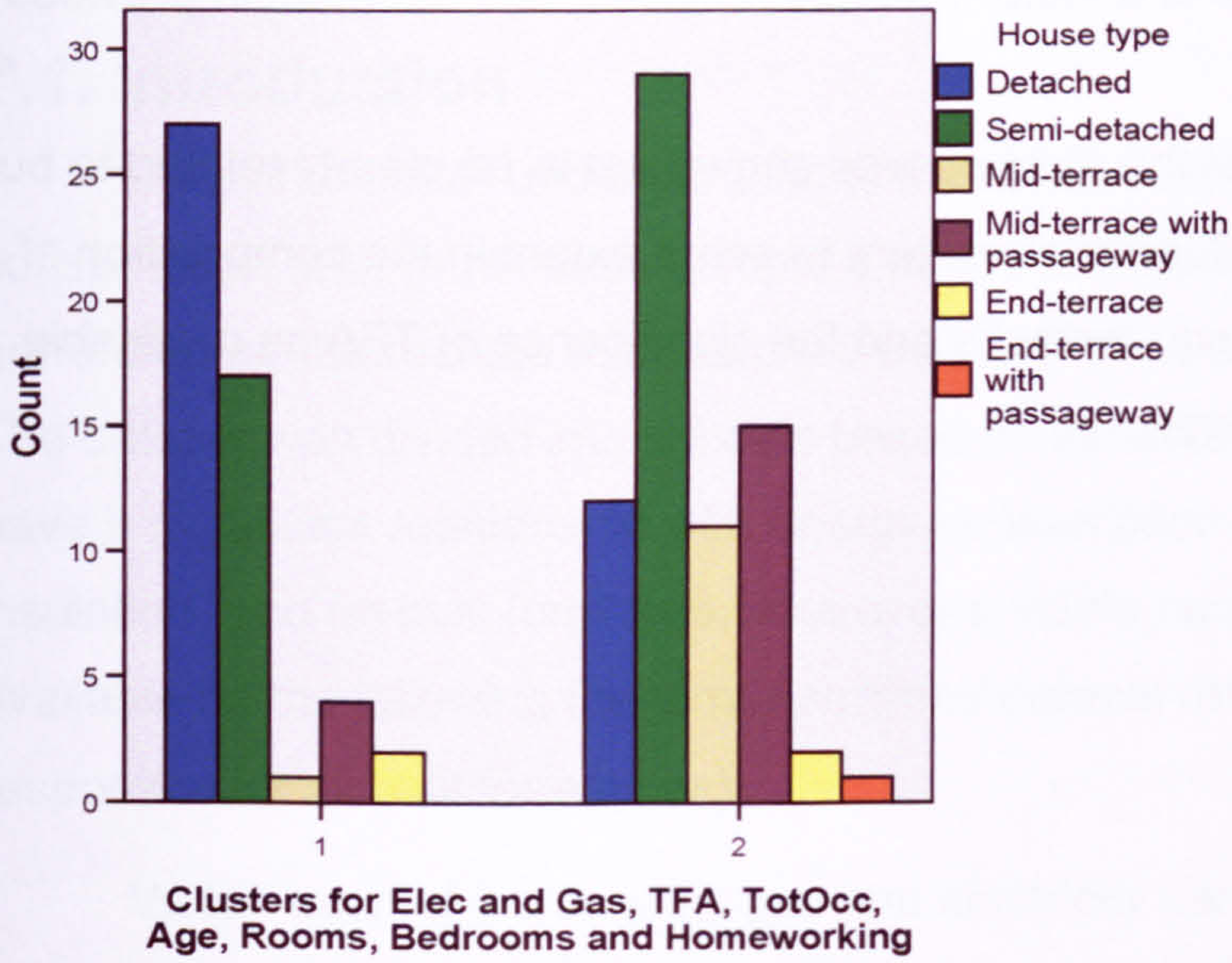


Figure 6.33. Composition by built form type of the clusters for the combined dataset clustered on energy consumption, TFA, occupancy, dwelling age, number of rooms, number of bedrooms and homeworking

The composition of the clusters by built form type (Figure 6.33) shows that even after accounting for the impact of the other variables the differentiation between the two clusters was still not centring on built form type. It must be concluded that, although built form is known to have an impact on domestic energy consumption (e.g. Yannas, 1994) at this level of analysis and within the limits of the dataset significant effects are not observable.

6.9. Chapter summary

This chapter has described the use of two-step cluster analysis on the energy consumption data for the dwellings in the combined dataset and the three samples. This led to the discovery of clusters of higher and lower energy consuming dwellings within the datasets that could be explained by a common set of variables: TFA, total occupancy, dwelling age, number of rooms, number of bedrooms, and to a lesser extent homeworking. The first five of these variables form the basis for which to assess the explanatory power of the additional variables used in the analyses that follow, whilst the significance of homeworking is analysed further as this is a factor that has received little attention in previous studies.

The composition of the clusters was shown not to be clearly related to built form type, however its influence is evident to some extent in the composition of the clusters for the Leicester terraces and the significance of TFA as a variable for determining the clusters.

Chapter 7. Further Exploratory Analysis using Simple Regression

7.1. Introduction

To gain a better understanding of the distributions of the energy consumption data within each sample a series of simple linear regressions was performed on the records that matched with floor area and consumption data. The dataset was divided into subsets based on variables known or expected to have a significant relationship with energy consumption (for example wall insulation) and on built form type, wherever a viable number of responses was available (in the following the term *combined dataset* refers to subsets containing responses for all built form types).

Within each of the subsets gas and electricity consumption were regressed against total floor area (TFA) and the strength of the relationships were used to identify variables that seemed most promising for more detailed analyses. Dwelling floor area is known to influence energy consumption (Carbon Trust 2006, Hendron & Eastment, 2006, Walsh et al., 2003, and Clinch et al., 2000) and was also found to be a significant determining variable for the clusters of energy consumers found in the data (chapter 6). Gas and electricity consumption were also regressed directly against those numerical response variables with distributions wide enough to merit this analysis (e.g. the number of energy efficient light bulbs in use).

Simple linear regression was used as an exploratory technique to expand the results from the cluster analyses phase and to investigate other possibilities in the dataset. In this phase the data was investigated for potential outliers and subsets with non-viable numbers of records were identified. Scatter plots were produced for each viable regression and visually inspected in order to assess how accurately the calculated correlations reflected the distribution of the data rather than relying on the r^2 and p-values alone.

This method was considerably more time intensive than simply calculating the r^2 values without producing the plots, but enabled the investigation of the distributions of the data for outliers and errors that may have occurred during the data entry process, as well as providing a visual representation of each regression (which would not be possible with multiple regression). Using Excel p-values have to be calculated using a separate tool that requires the removal of any missing records and therefore they have been calculated only for the r^2 values reported here. P-values are reported to 3 decimal places.

This chapter presents and discusses the most interesting results from this phase of the study (a full table of r^2 values can be found in Appendix 7). These results were used in conjunction with the cluster analyses discussed in the previous chapter to inform the selection of variables for the concluding confirmatory analyses phase (Chapter 8).

The consumption data used in this study represents the first time the DTI has released this data to researchers, and whilst it cannot be expected to be as reliable as that collected as part of longitudinal studies using energy meters it is still the most reliable means of obtaining this information for large numbers of dwellings where a more intensive approach would be infeasible in terms of time and resources. It also represents the only source of this information for such large numbers of dwellings that is likely to be made available to researchers for the foreseeable future.

7.1.1. Potential outliers in the data

During several of these analyses potential outliers were removed to assess their impact on the calculated correlations, however making a decision over whether to remove a record completely has to involve consideration of the source of the data, and hence its likely reliability. The table given in Appendix 7 includes notes on those cases where potential outliers were removed, however the majority of the correlations found were weak and where the removal of potential outliers did notably improve the correlations they were either already strong or the variable was also highlighted by other correlations within the variable category. Overall, the evidence from these analyses indicated that the data was fit for purpose.

7.2. Energy consumption regressed against TFA

When simple regressions of electricity data and gas data against TFA were carried out for the combined dataset produced strikingly different results. The r^2 values were 0.0994 and 0.2857 respectively both with p-values of 0 (Figures 7.1 and 7.2), thus confirming expectations that the relationship between energy consumption and TFA would be stronger for gas than for electricity. Electricity consumption is likely to be explained by a much wider range of factors than gas (Tso & Yao, 2003).

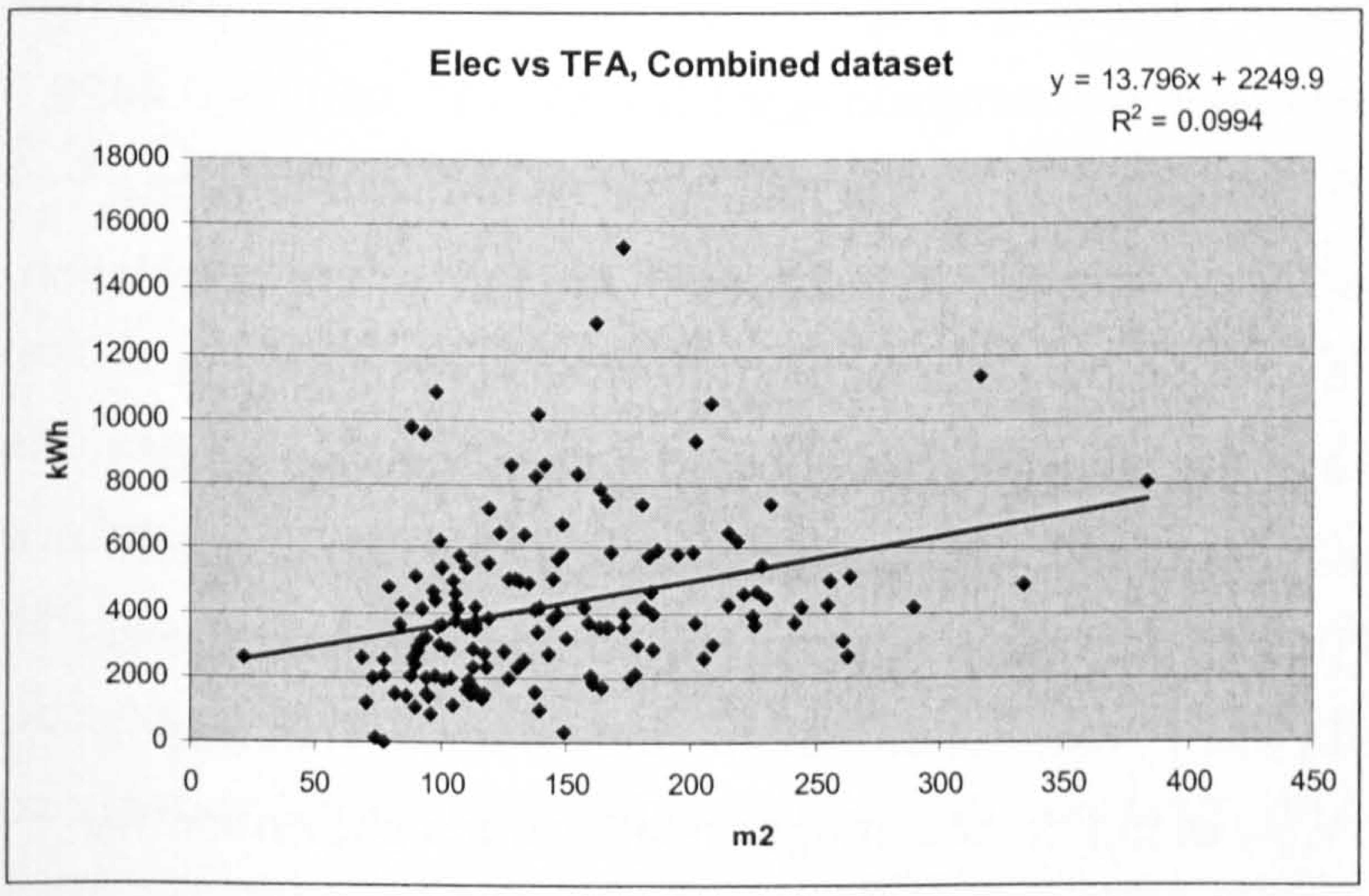


Figure 7.1. Electricity consumption regressed against TFA, combined dataset

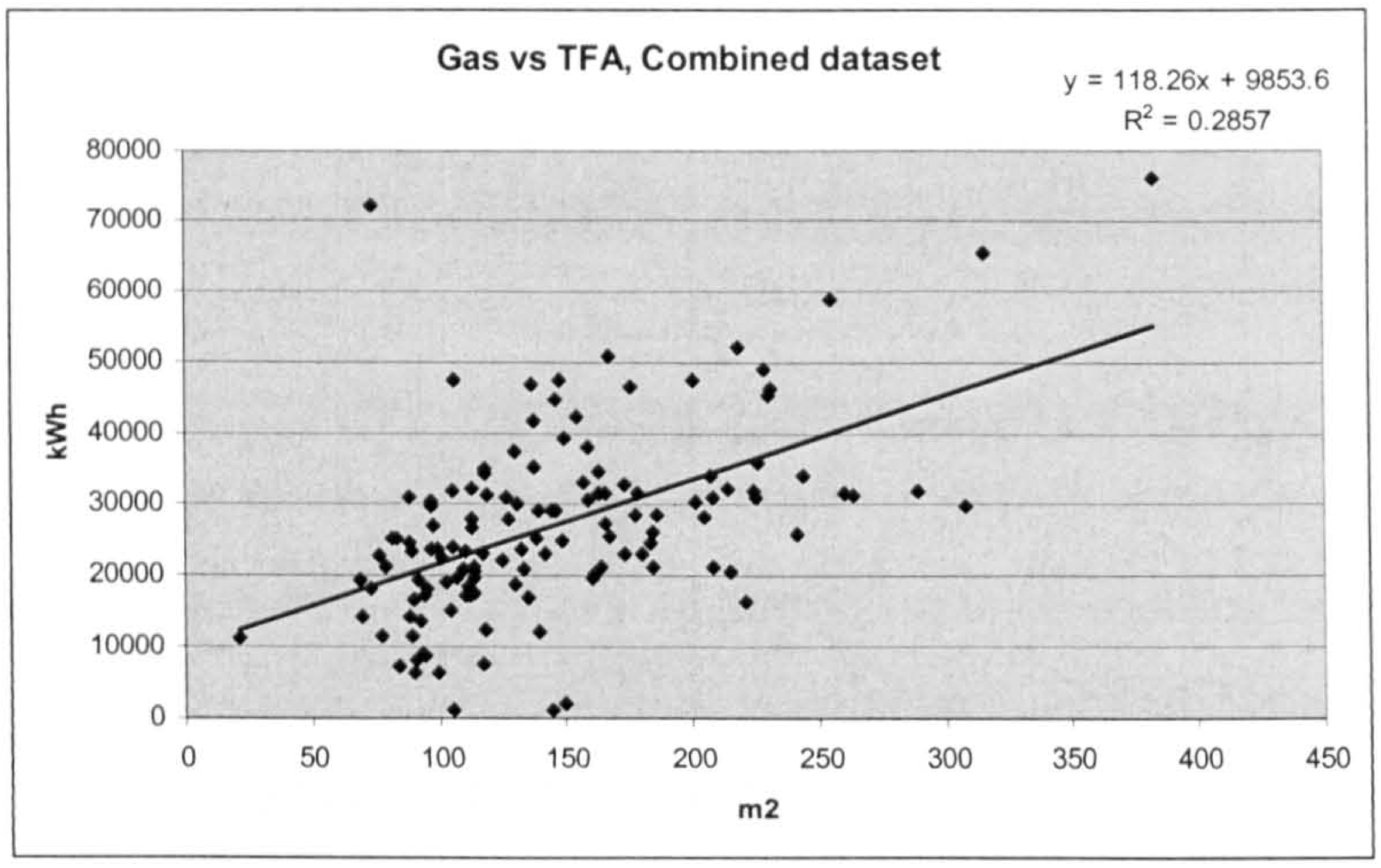


Figure 7.2. Gas consumption regressed against TFA, combined dataset

For the three samples the best r^2 (0.4023, p-value 0) was for gas against TFA for the Sheffield detached dwellings (Figure 7.3). For the Leicester dwellings split by built form regressing gas consumption against TFA produced r^2s 0.4429 and 0.4113 (p-values 0.013 and 0.002) for the mid-terraces and mid-terraces with passageways respectively, although in the case of the former the correlation appeared to be heavily leveraged by a cluster of smaller, lower consuming dwellings and in the case of the latter the plot showed a very high degree of scatter. In addition the number of records was reduced to 14 and 20 in each case. The regression of gas consumption against TFA for the Sheffield semis produced an unexpectedly low r^2 value of 0.0787 (p-value 0.056). This was particularly surprising in view of the much stronger relationships shown for the other subsets and could not be explained with the available data or local knowledge.

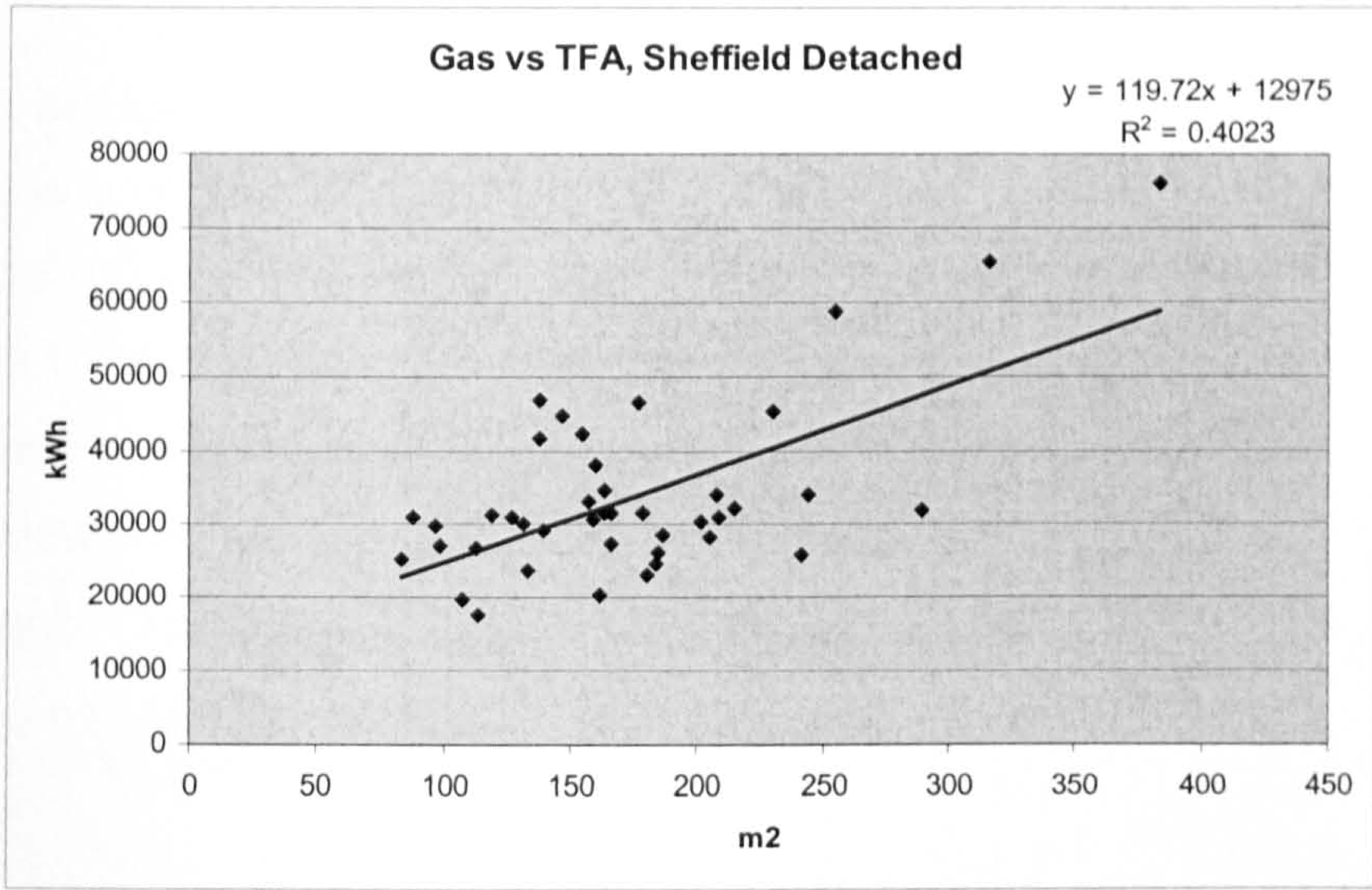


Figure 7.3. Gas consumption regressed against TFA, Sheffield detached

7.3. Occupancy

Occupancy is a key variable for energy consumption models and so the results for these regressions were of particular interest. However, this part of the analysis was problematic due to the relatively small total number of records available compared with the diversity of household compositions. The method of differentiating the dataset into subsets produced very small samples by occupancy levels. For this reason consumption was first plotted against total occupancy (adults plus children) before sub-dividing into groups representing the main categories of occupancy in each study area – single person households, two person households, family households, and in the case of the combined dataset and the Sheffield detached sample, three person households.

For the combined dataset the relationships between total occupancy and electricity and gas consumption were similar, with r^2 values of 0.1814 and 0.2089 respectively, p-values both 0 (Figures 7.4 and 7.5) supporting the existing evidence that occupancy is a useful predictor of both types of energy consumption. The relationship between occupancy and TFA was much weaker (r^2 value 0.0829, p-value 0) despite visual inspection revealing an apparently similar scatter for all three plots.

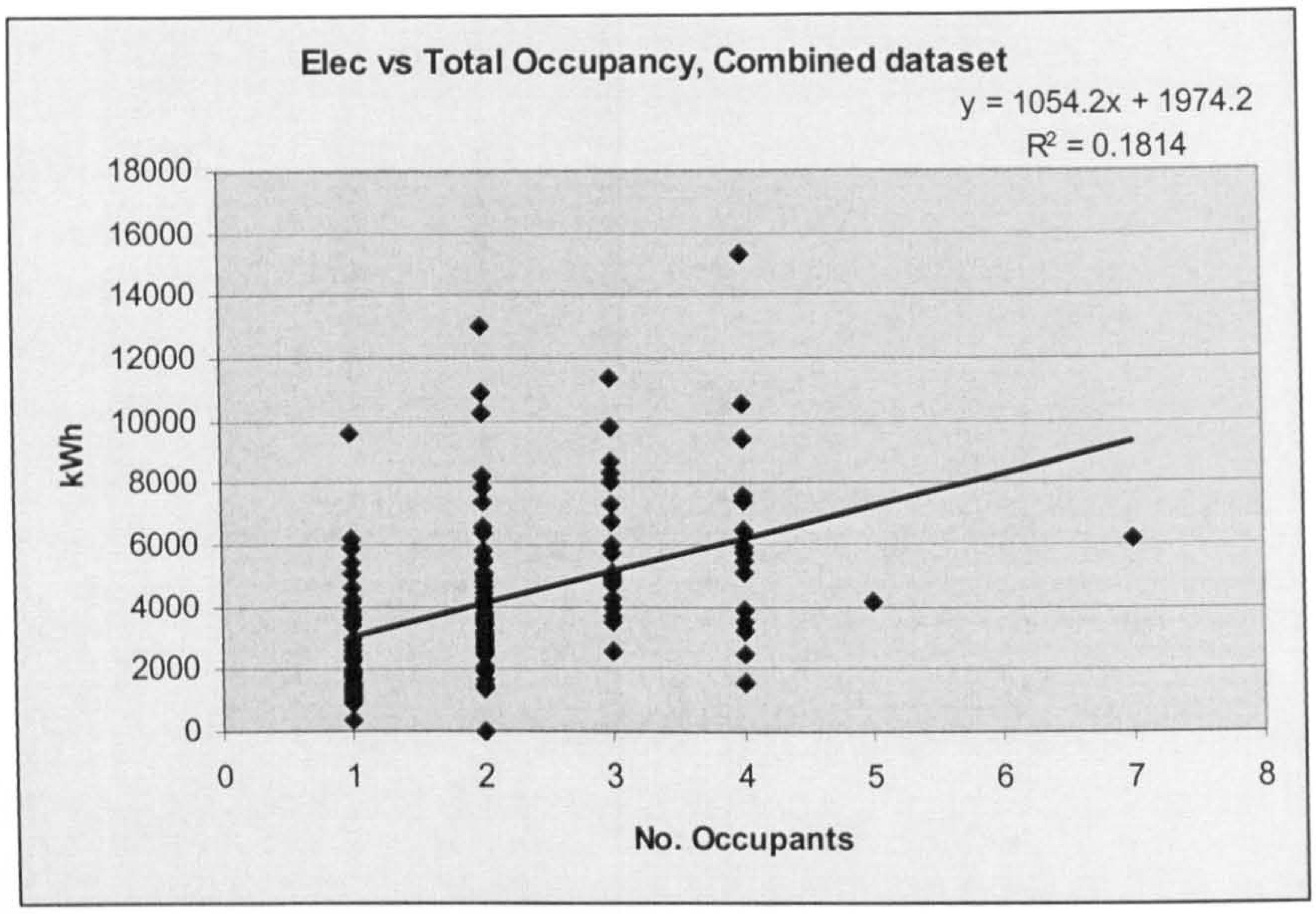


Figure 7.4. Electricity consumption regressed against total occupancy, combined dataset

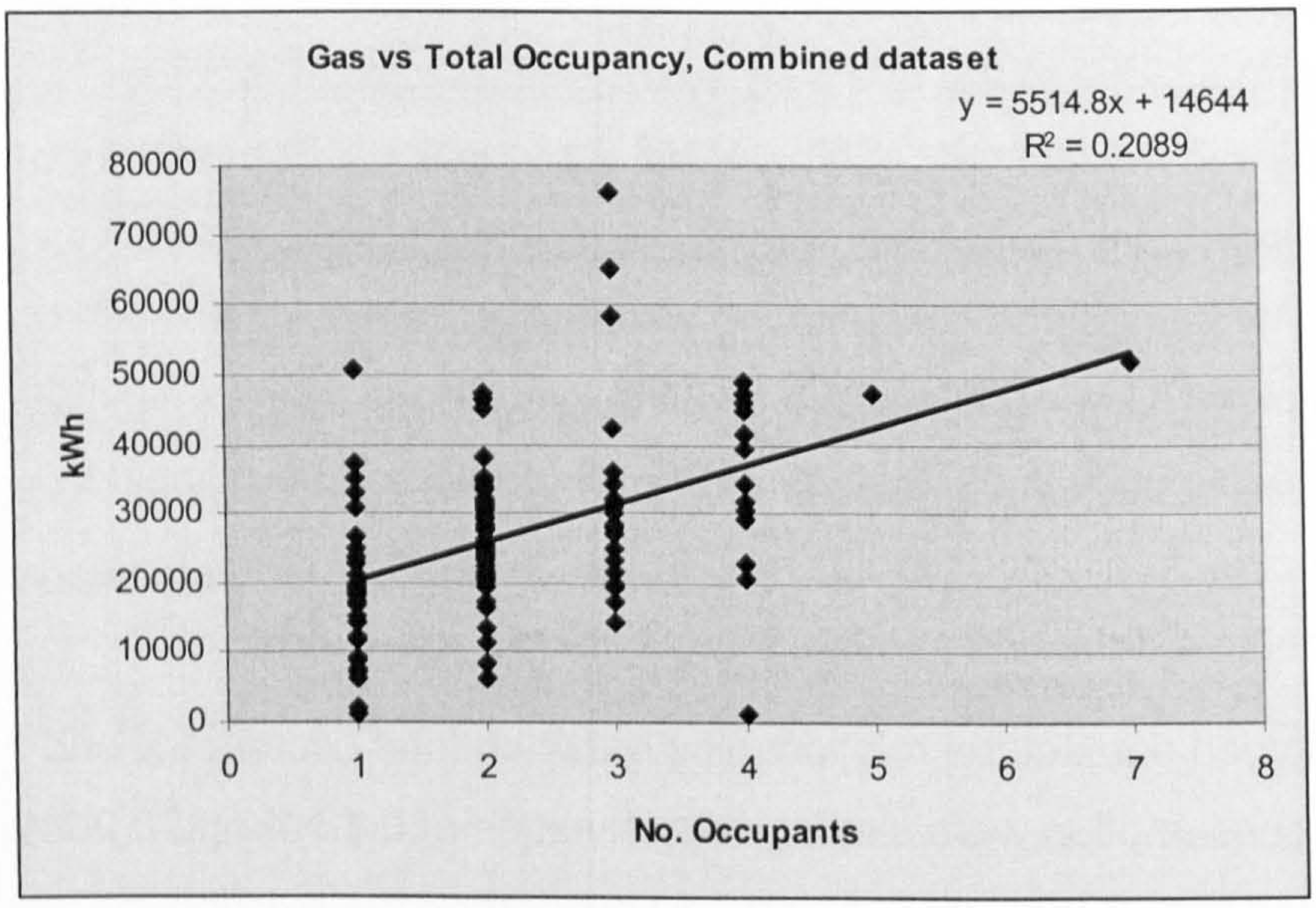


Figure 7.5. Gas consumption regressed against total occupancy, combined dataset

When the dataset was grouped by occupancy no notable relationships were found between electricity consumption and TFA, the strongest being an r^2 value of 0.1667 (p-value 0.131) for the three person households, based on only 15 records. The results were better for gas consumption, with r^2 values of 0.2294, 0.1938, 0.7880 and 0.2759 for single, two and three person and family households respectively (p-values 0.006, 0, 0, and 0.025, Figures 7.6 to 7.9). However, the strong relationship found for the three person dwellings is based on only 13 points.

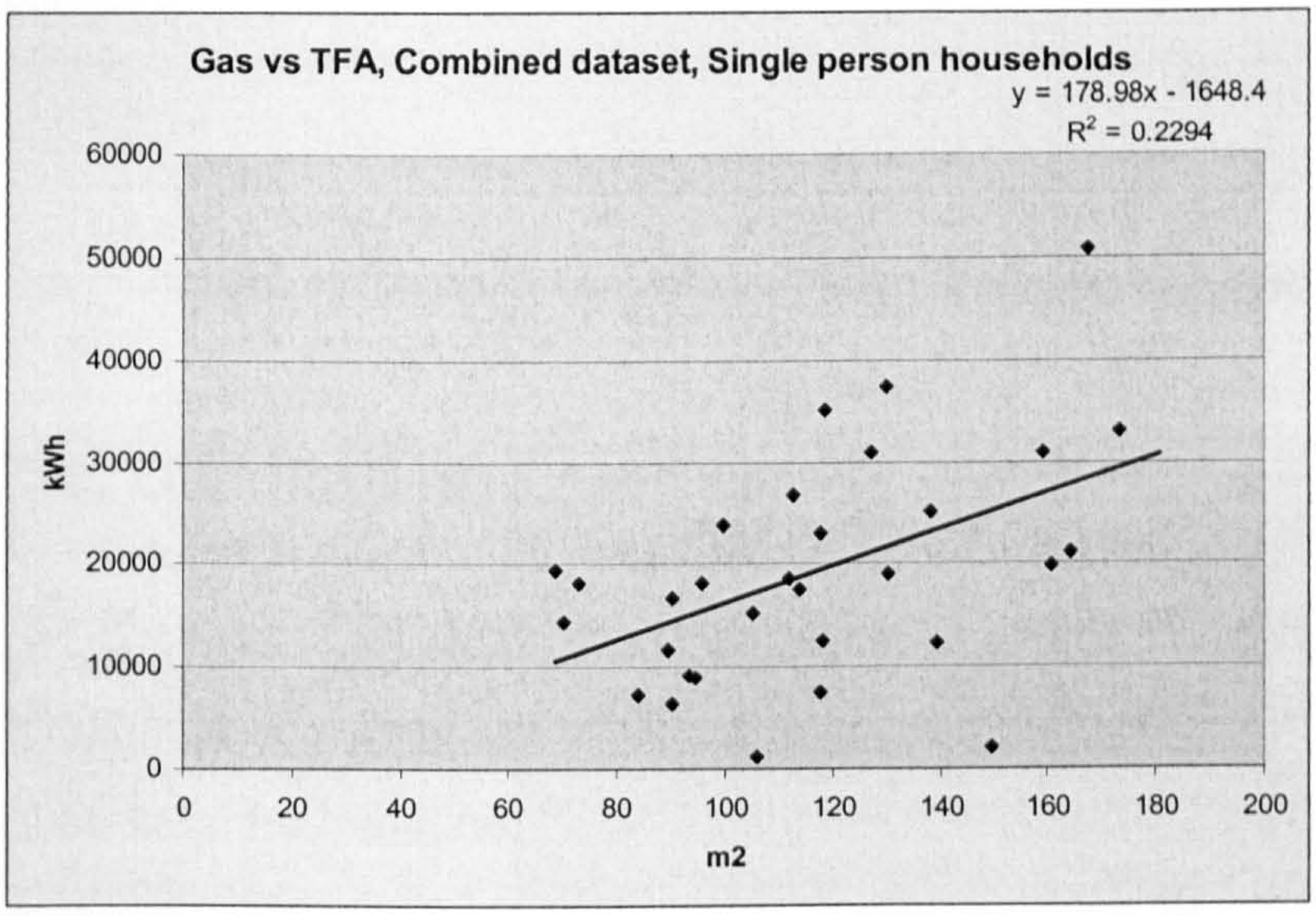


Figure 7.6. Gas consumption regressed against TFA, combined dataset, single person households

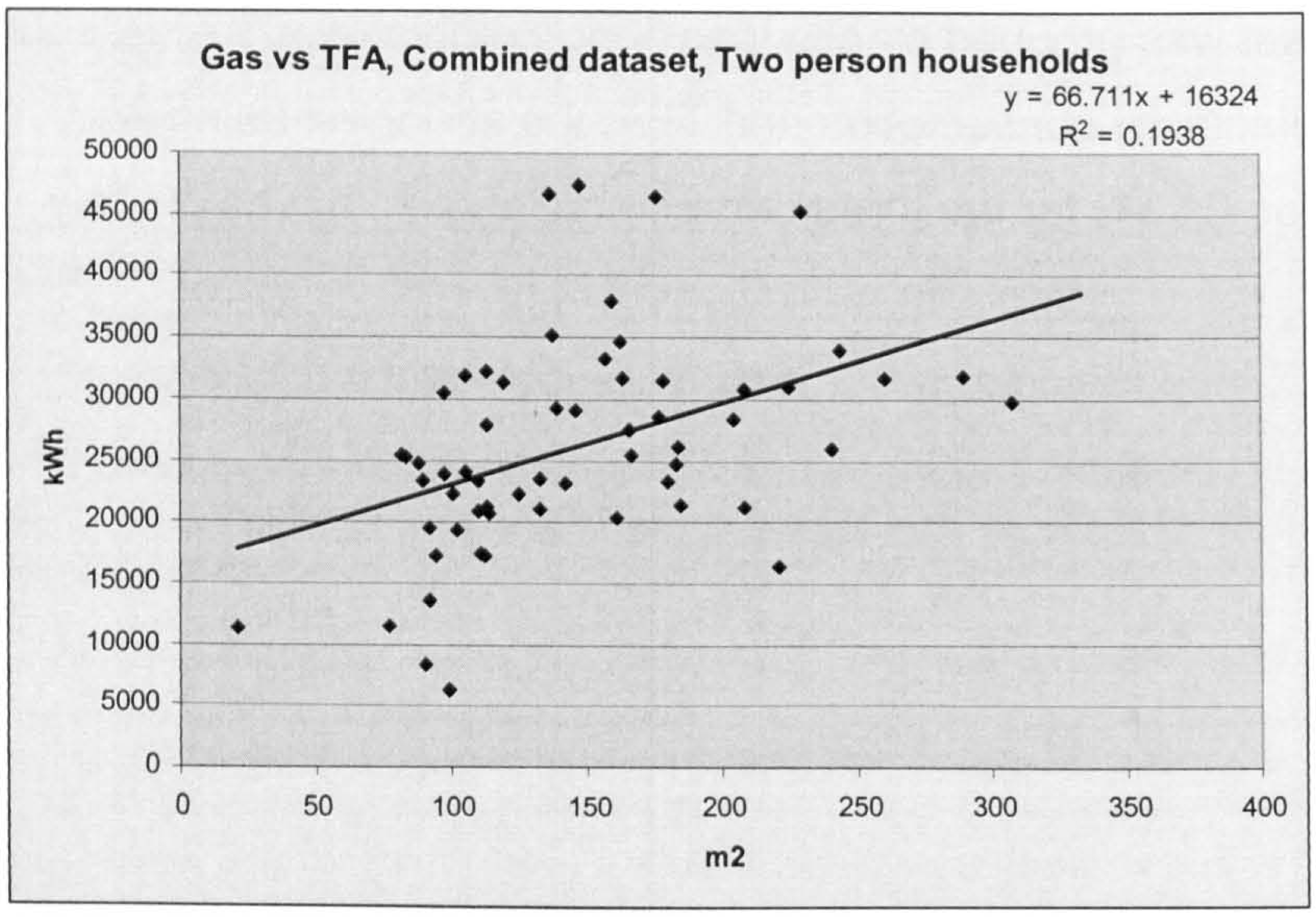


Figure 7.7. Gas consumption regressed against TFA, combined dataset, two person households

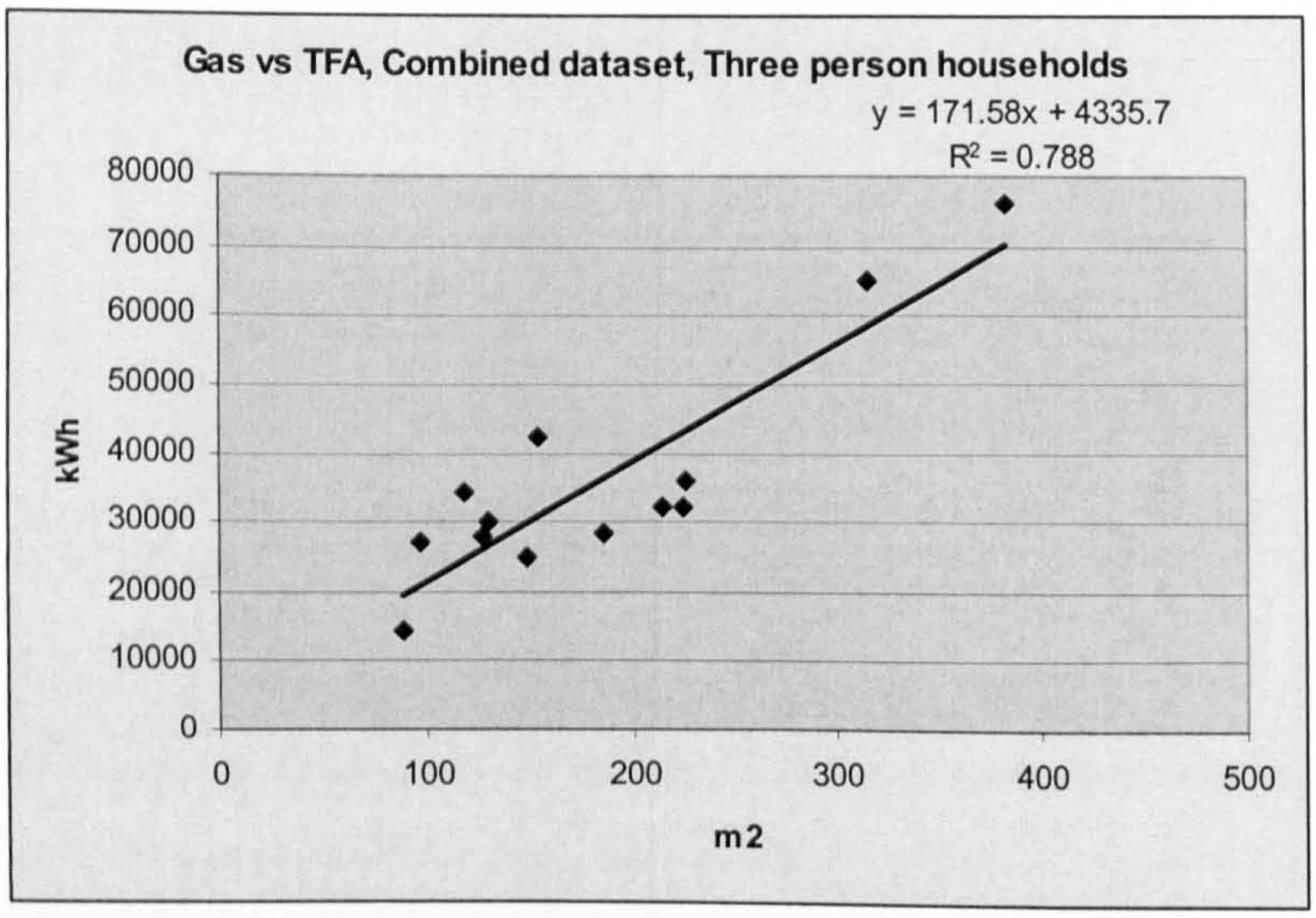


Figure 7.8. Gas consumption regressed against TFA, combined dataset, three person households

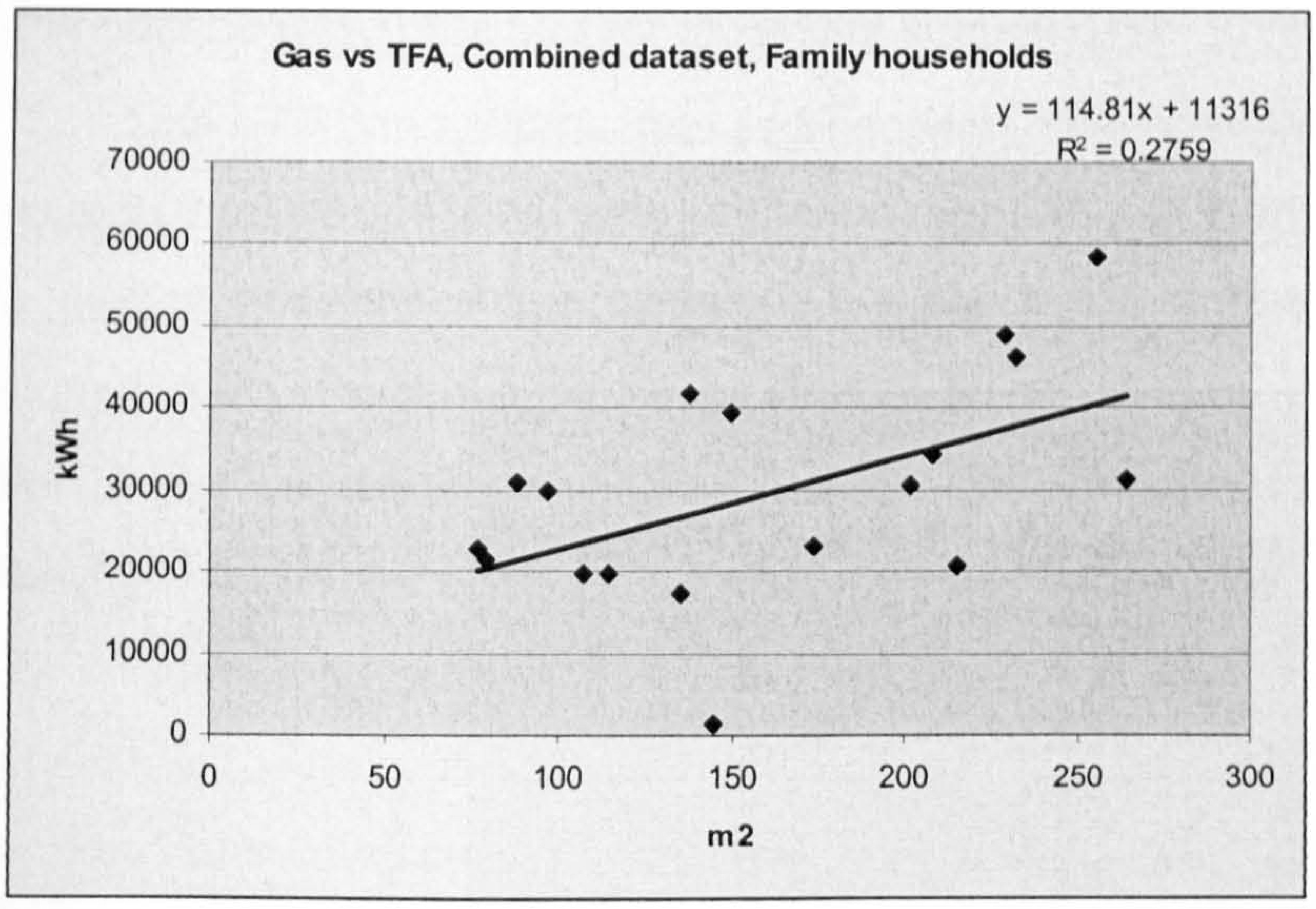


Figure 7.9. Gas consumption regressed against TFA, combined dataset, family households

7.4. Dwelling age

For subsets by dwelling age a very strong relationship was found between TFA and gas consumption in the 1930-49 age bracket (r^2 value 0.9054, p-value 0, Figure 7.10). Although this plot consists of only 10 points they show a very close fit to the trendline.

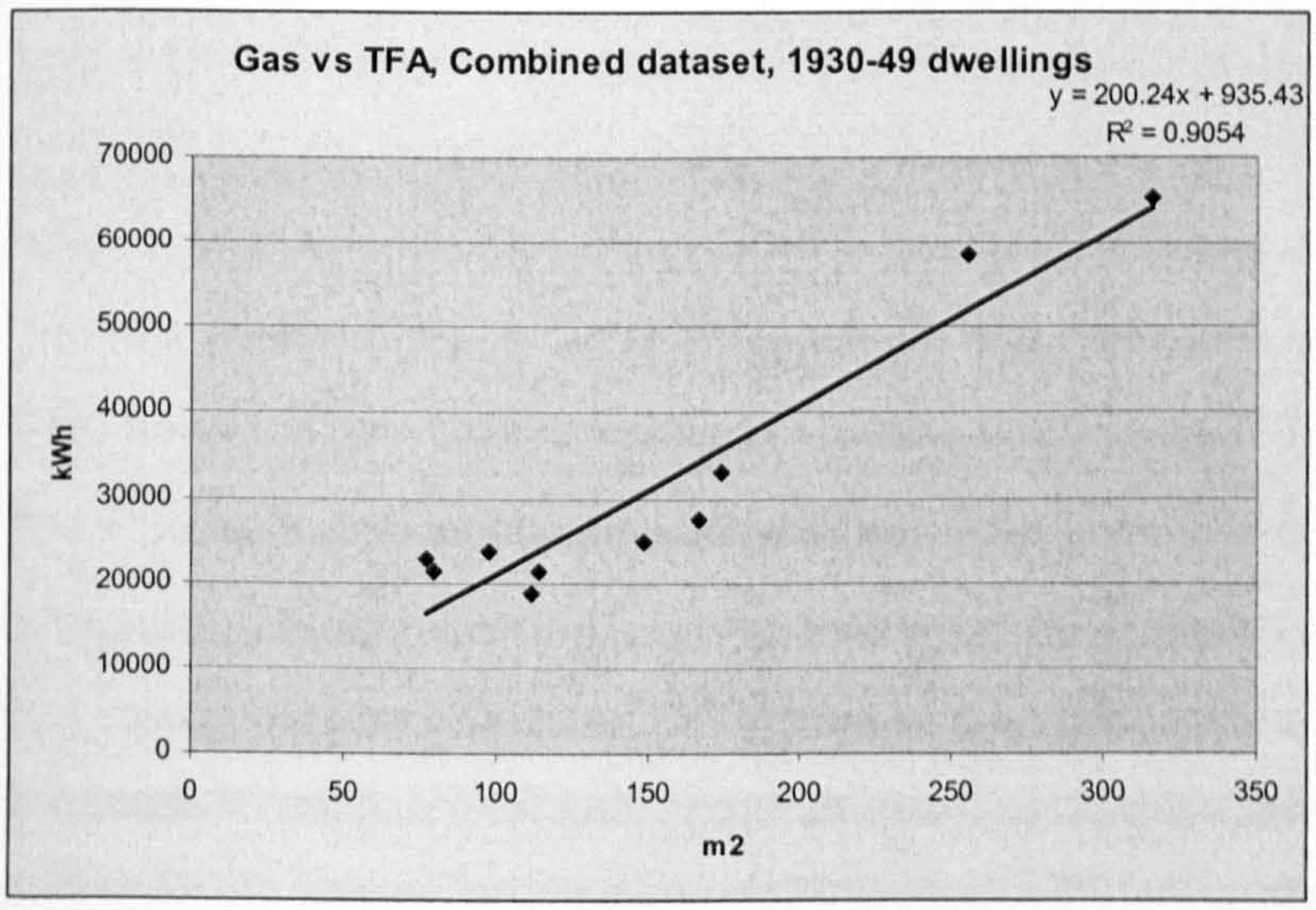


Figure 7.10. Gas consumption regressed against TFA, combined dataset, 1930-49 dwellings

Another notable relationship between gas consumption and TFA was found for dwellings in the 1900-29 age bracket (r^2 value 0.4634, p-value 0, Figure 7.11) which is calculated from 22 points and shows a greater degree of scatter.

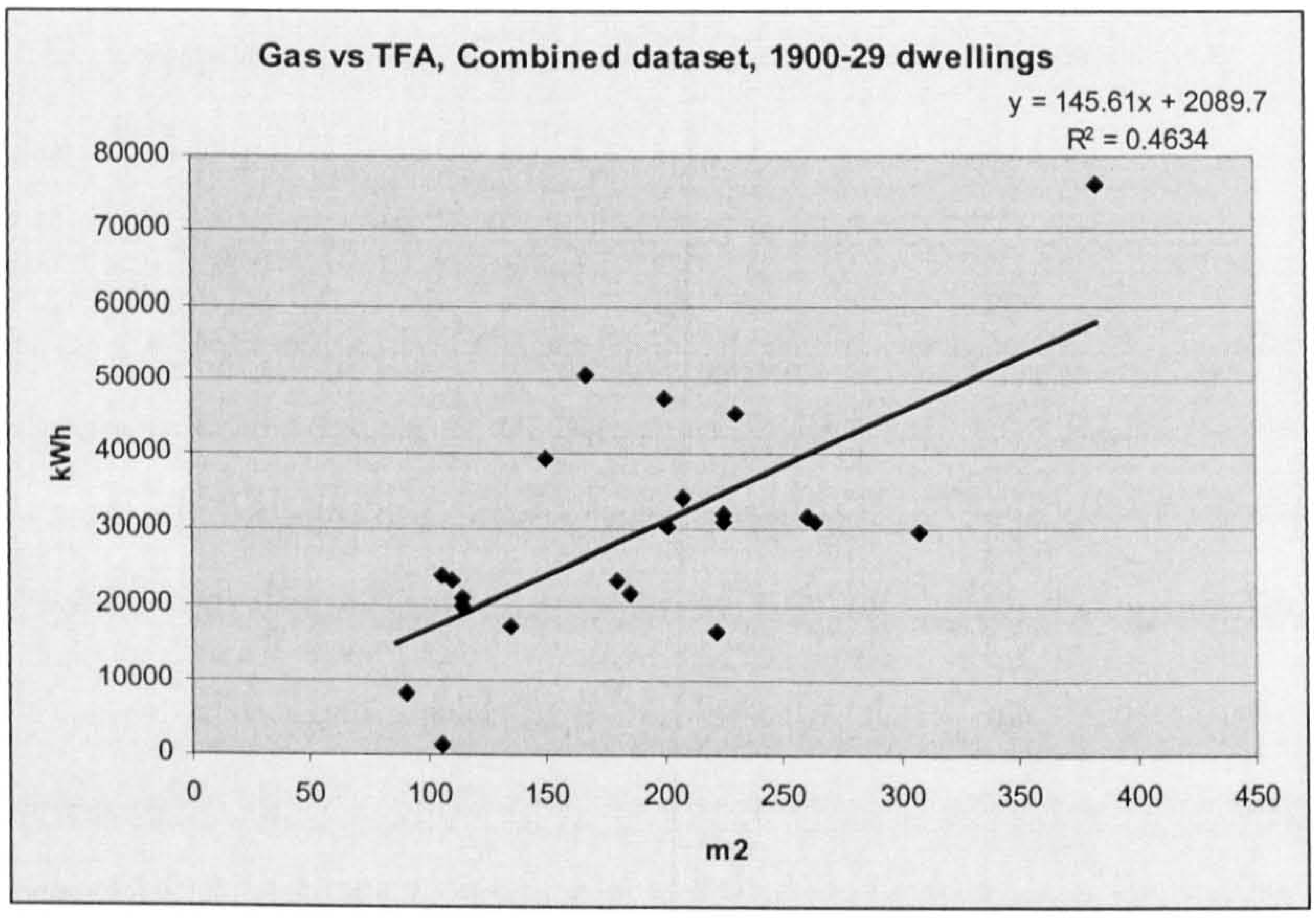


Figure 7.11. Gas consumption regressed against TFA, combined dataset, 1900-29 dwellings

However, this relationship was weaker for the dwellings in the other age brackets with r^2 values of 0.2051, 0.0299 and 0.0200 (p-values 0.056, 0.279, and 0.0520) for the pre-1900, 1950-66 and 1966-76 dwellings respectively.

For electricity consumption regressed against TFA the only r^2 values above 0.1 were found for the pre-1900 dwellings (0.1774, p-value 0.015) and for the 1930-49 dwellings (0.1896, p-value 0.181) however the latter was based on only 11 points.

In the case of Leicester, with its older and more homogeneous dwelling stock, two subsets were obtained, approximately 2/3 pre-1900 and 1/3 post-1900, although from local knowledge it seems probable that most are of similar age. For gas regressed against TFA both groups produced r^2 values of 0.2 (p-value 0.016 for the pre-1900 dwellings, 0.255 for the 1900-29 dwellings. No good correlations were obtained for electricity against TFA.

A much greater variation in dwelling age was evident amongst the Sheffield dwellings, although in general differentiation by age significantly reduced the r^2 values. The two exceptions to this were the r^2 value of 0.5413 (p-value 0.060) obtained for gas against TFA for the 7 semi-detached dwellings in the 1930-49 age bracket and an r^2 value of 0.9238 (p-value 0) obtained for gas against TFA for the 8 pre-1950 detached properties (Figure 7.12).

Although based on too few points to be meaningful, these results appear to explain the emergence of dwelling age as a determining variable for the energy consuming clusters discovered and discussed in chapter 6.

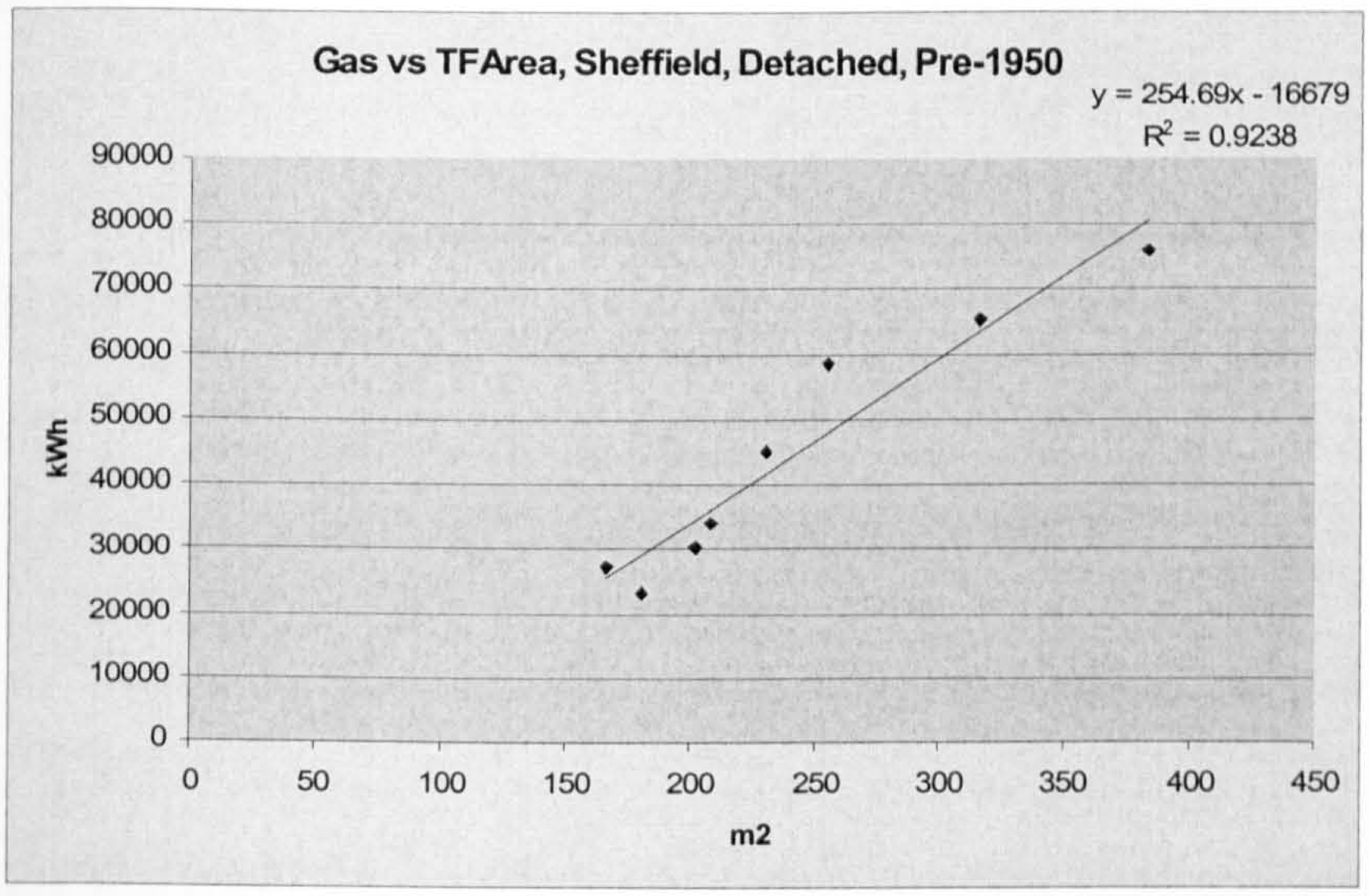


Figure 7.12. Gas consumption regressed against TFA, Sheffield detached, pre-1950

7.5. Numbers of rooms and bedrooms

As the numbers of rooms and bedrooms were found to be strongly related to the consumption clusters discovered in the data (chapter 6) it was expected that some relationships would be found between these variables and energy consumption and TFA. Simple regression confirmed this. For the combined dataset the r^2 value for the number of rooms regressed against TFA was 0.4285 (Figure 7.13) and this was only marginally lower (0.3772) for the number of bedrooms (Figure 7.14) both having p-values of 0.

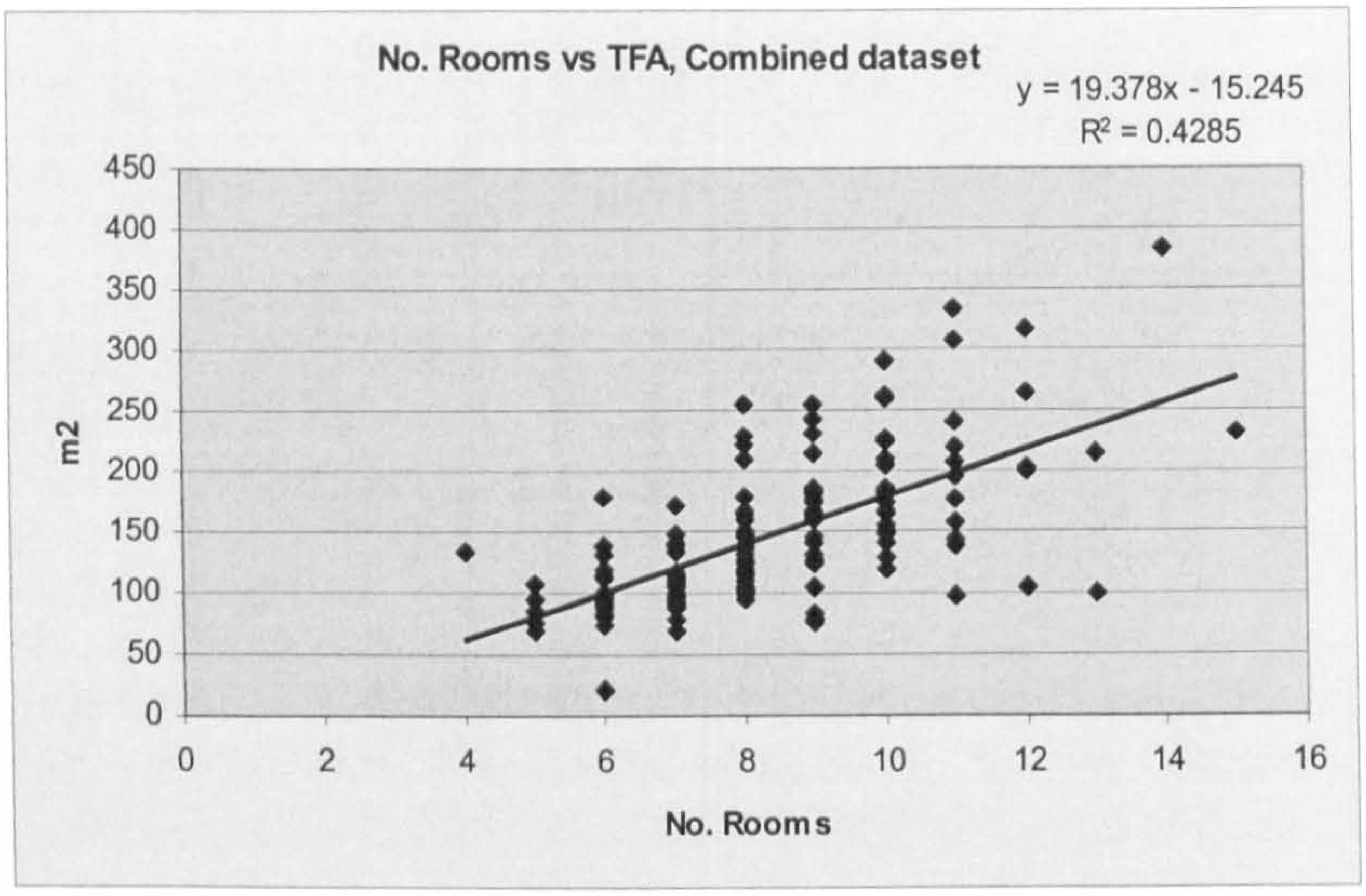


Figure 7.13. TFA regressed against the number of rooms, combined dataset

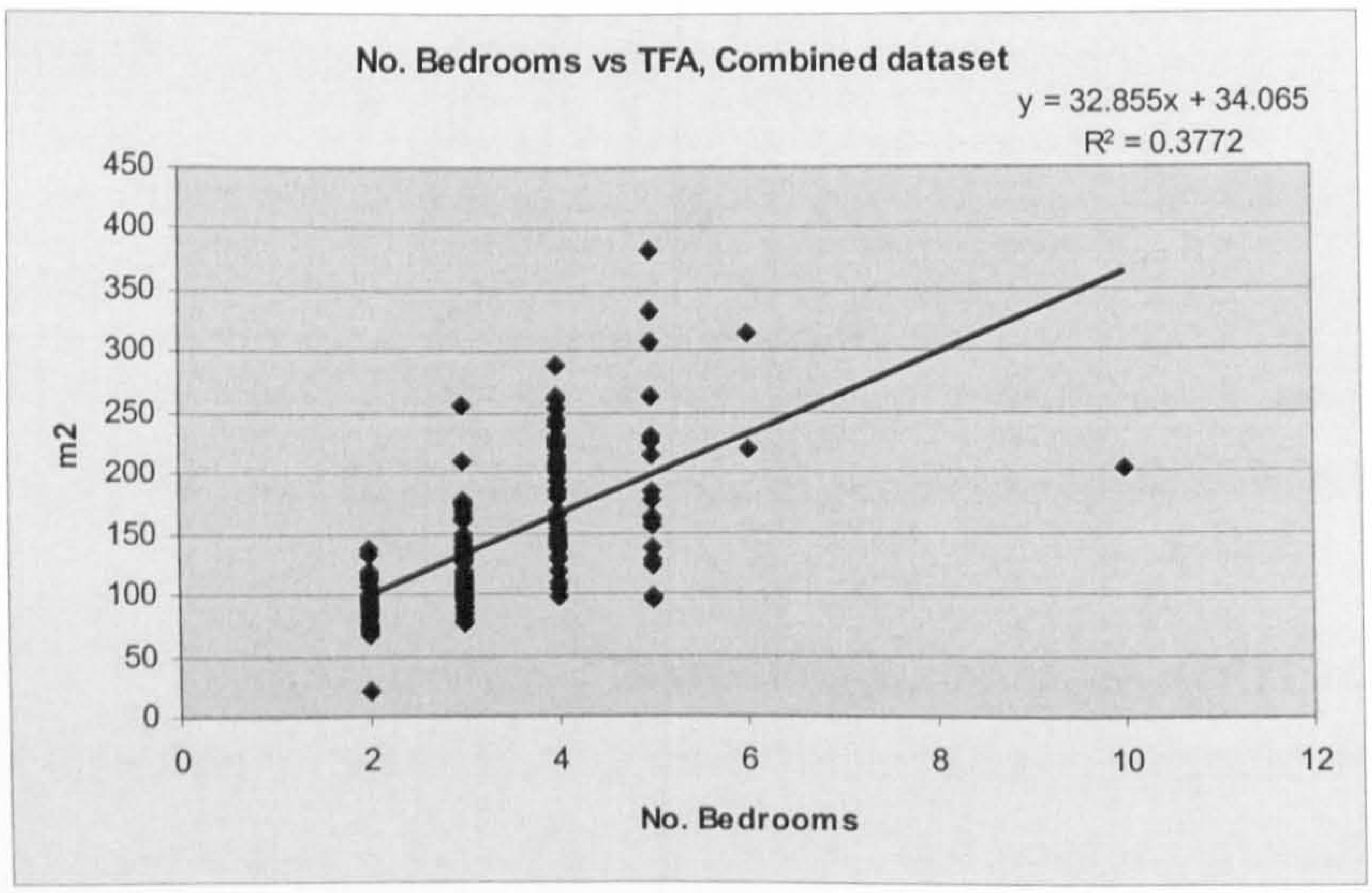


Figure 7.14. TFA regressed against the number of bedrooms, combined dataset

These were two of the categories for which it was possible to regress the consumption data directly against the variable, and this produced several interesting results. For gas consumption the relationship was stronger with the number of rooms (r^2 value 0.2040, p-value 0, Figure 7.15) compared to the number of bedrooms (r^2 value 0.1894, p-value 0, Figure 7.16).

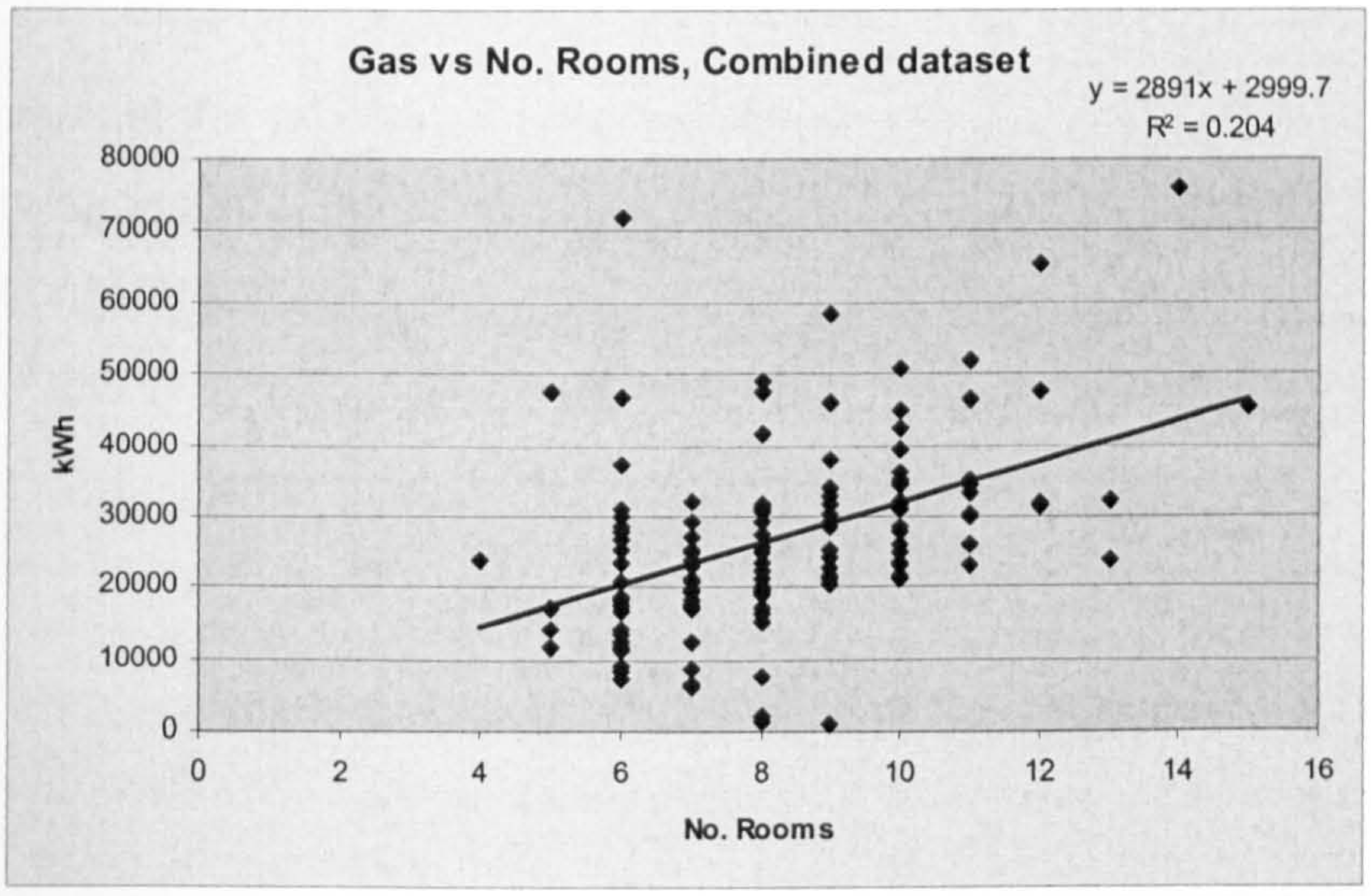


Figure 7.15. Gas consumption regressed against the number of rooms, combined dataset

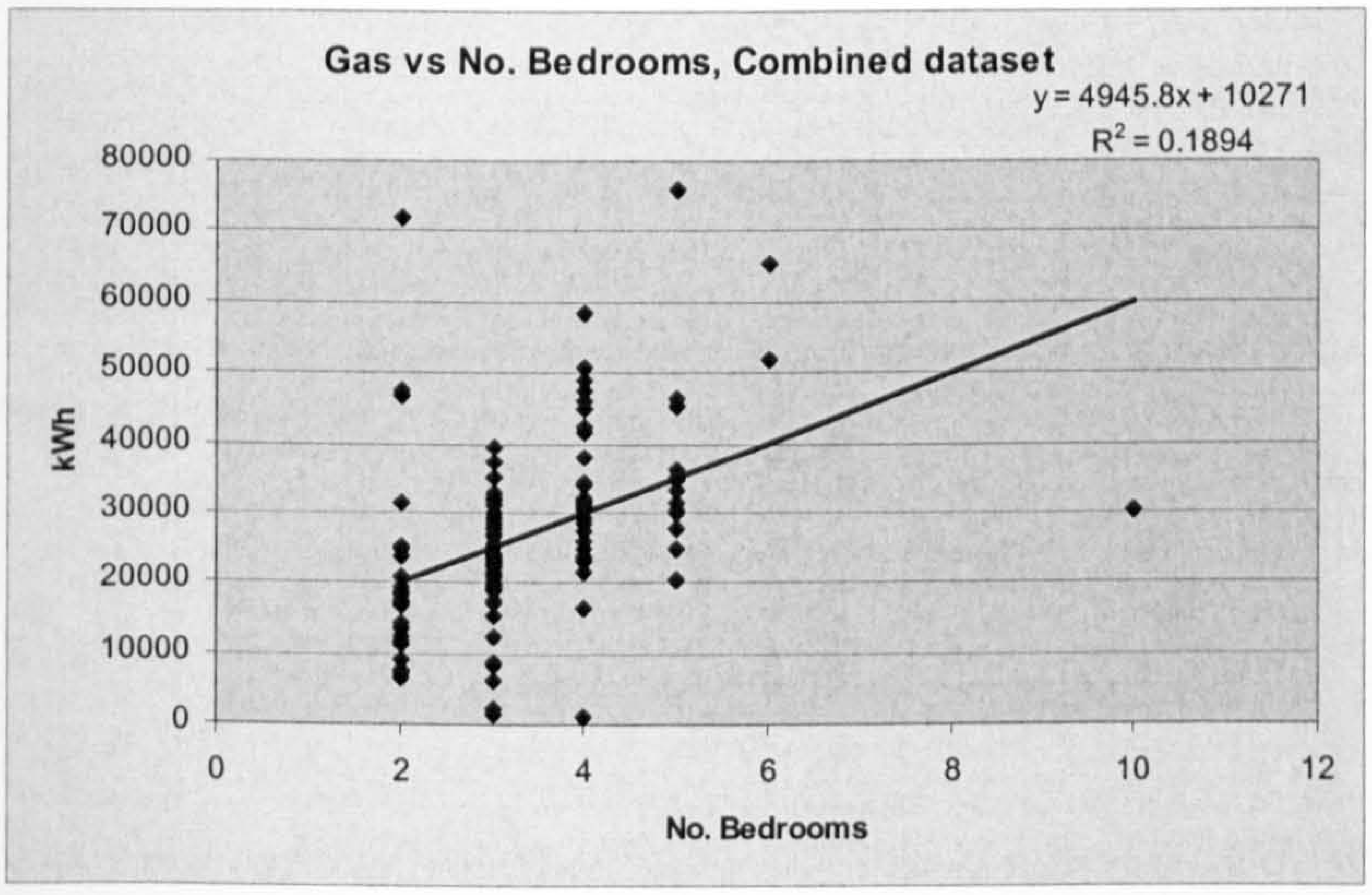


Figure 7.16. Gas consumption regressed against the number of bedrooms, combined dataset

However, for electricity consumption the relationship was stronger with the number of bedrooms (r^2 value 0.2410, p-value 0, Figure 7.17) compared to the number of rooms (r^2 value 0.1234, p-value 0, Figure 7.18).

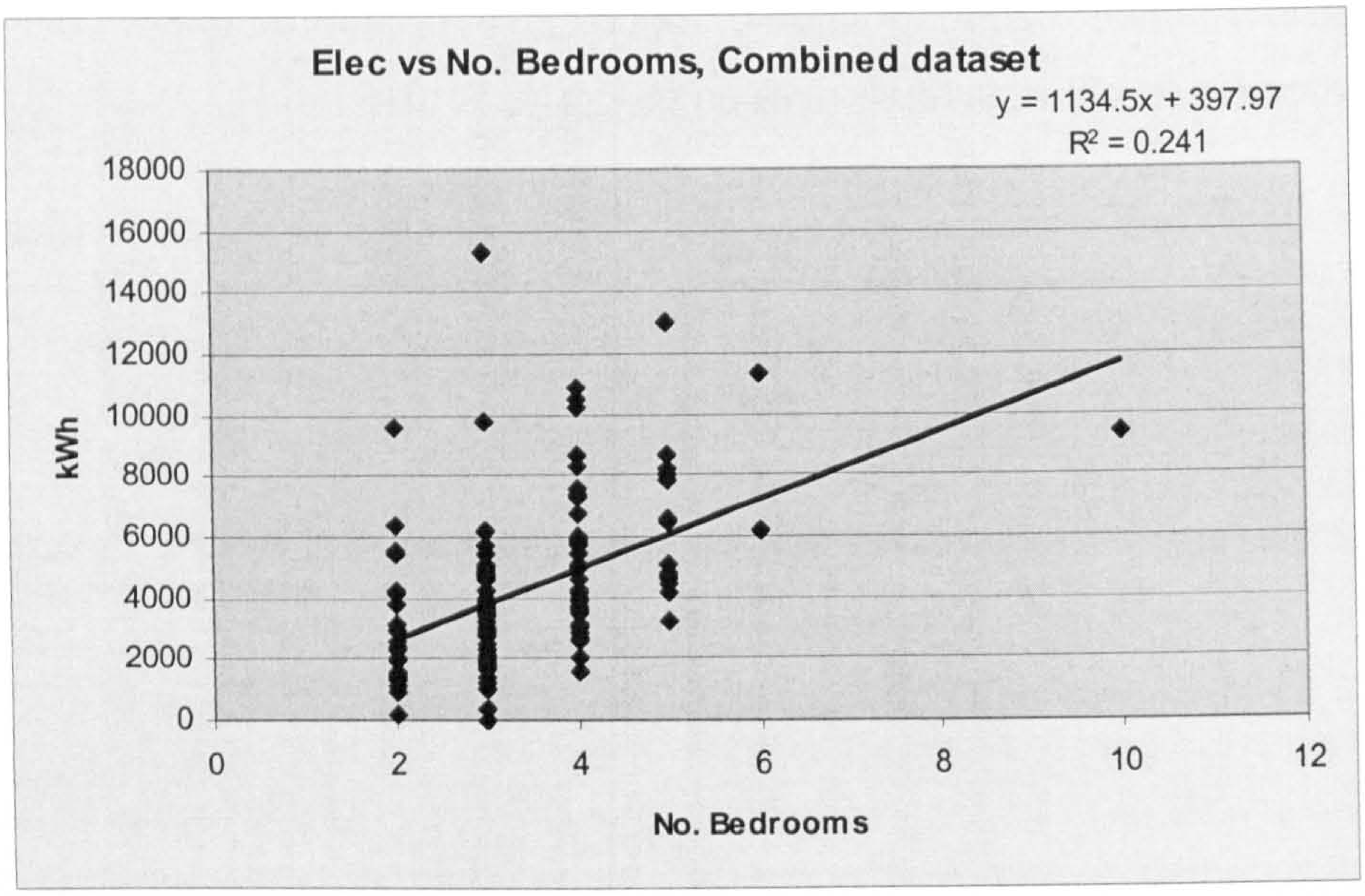


Figure 7.17. Electricity consumption regressed against the number of bedrooms, combined dataset

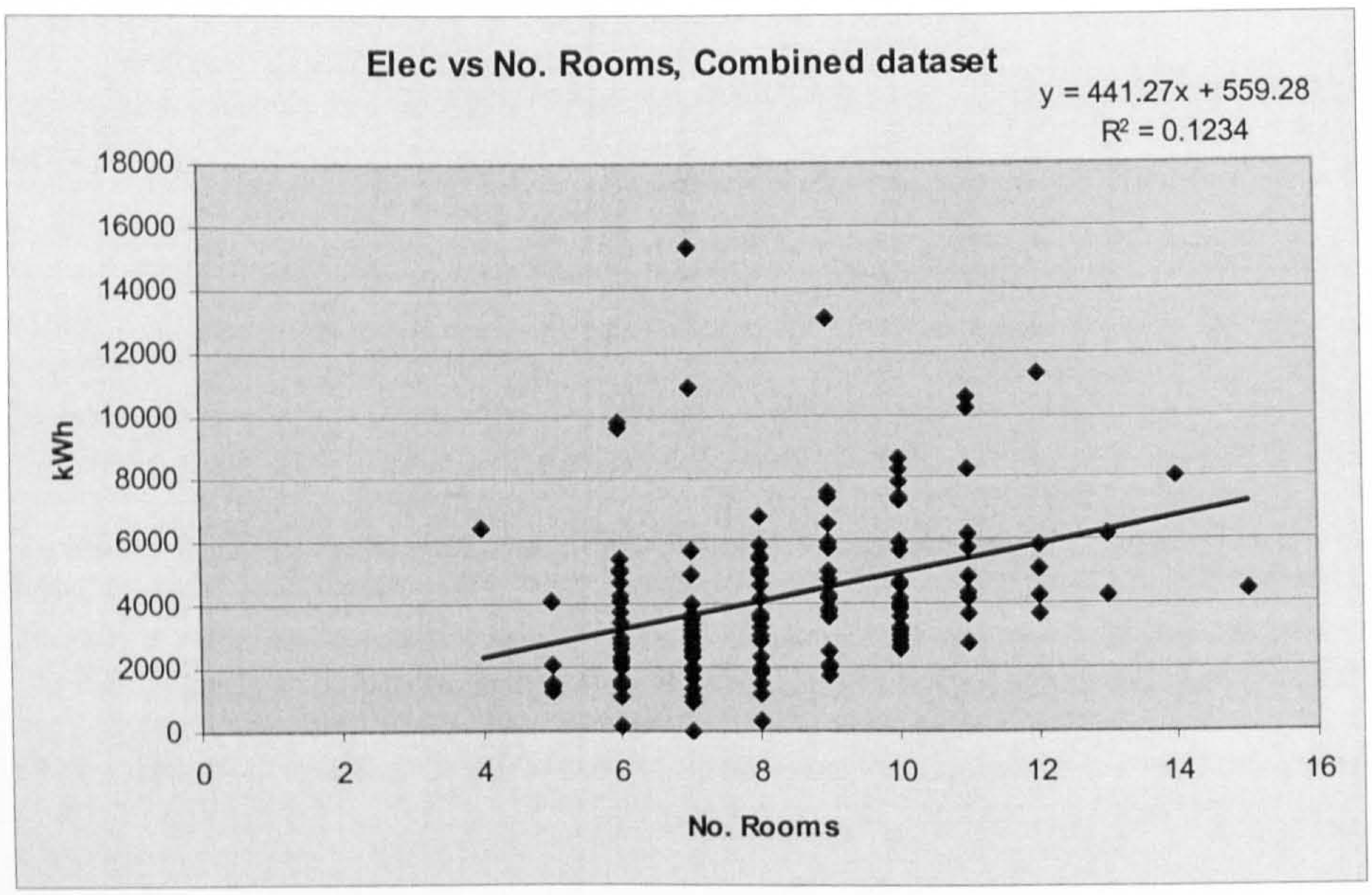


Figure 7.18. Electricity consumption regressed against the number of rooms, combined dataset

These results support the evidence that differences in gas consumption is more closely related to dwelling size as its main use is for heating, whereas the stronger relationship between electricity consumption and the number of bedrooms suggests that this is more dependent on factors related to occupancy which may be approximated more accurately using this variable.

For each built form type the regression of electricity and gas consumption against the number of rooms and bedrooms failed to show any significant relationships. However regression of TFA against these variables was of considerable value in understanding the dwelling stock. The following three plots (Figures 7.19 to 7.21) show these regressions for the three study areas.

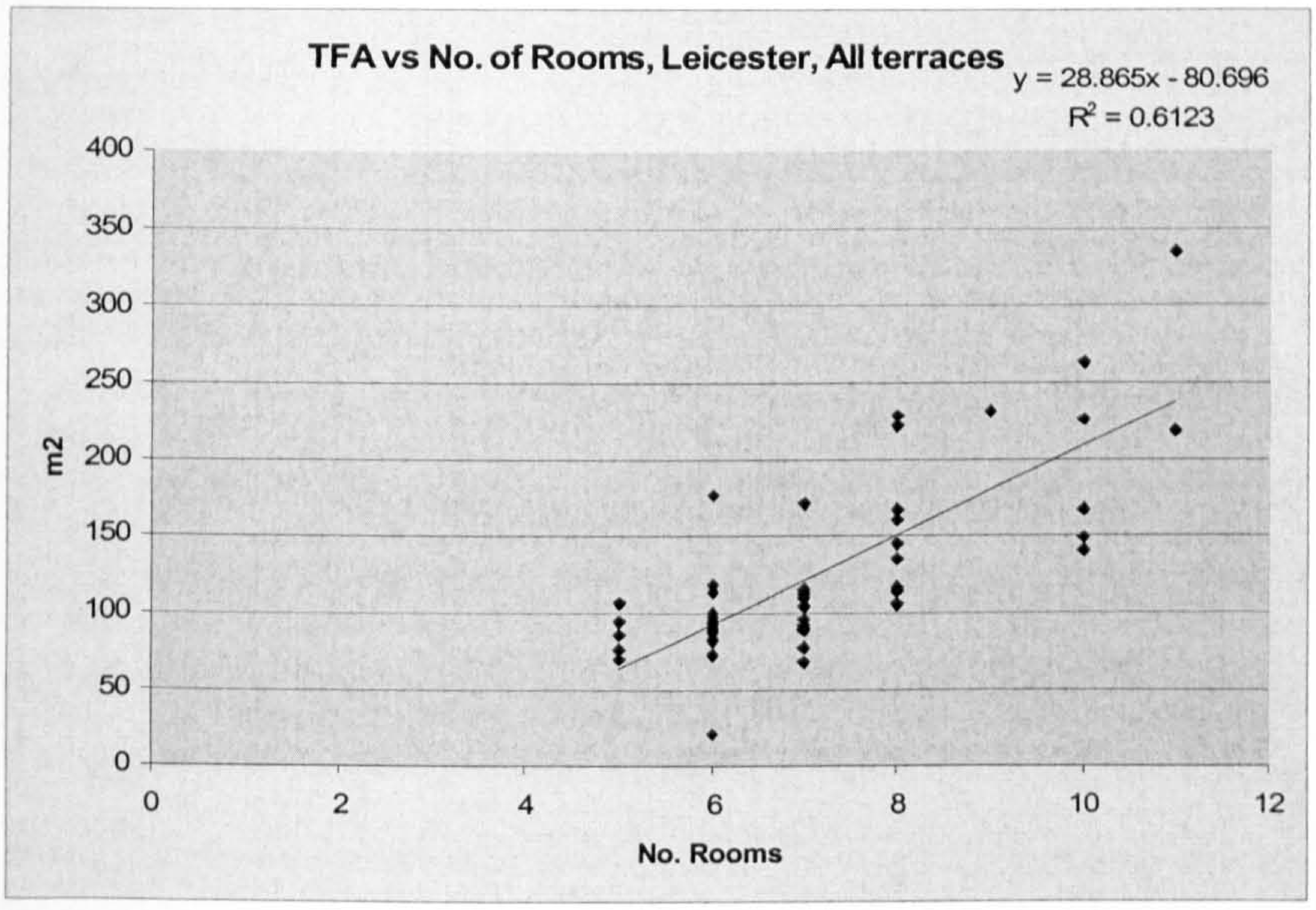


Figure 7.19. – TFA regressed against the number of rooms, Leicester terraces

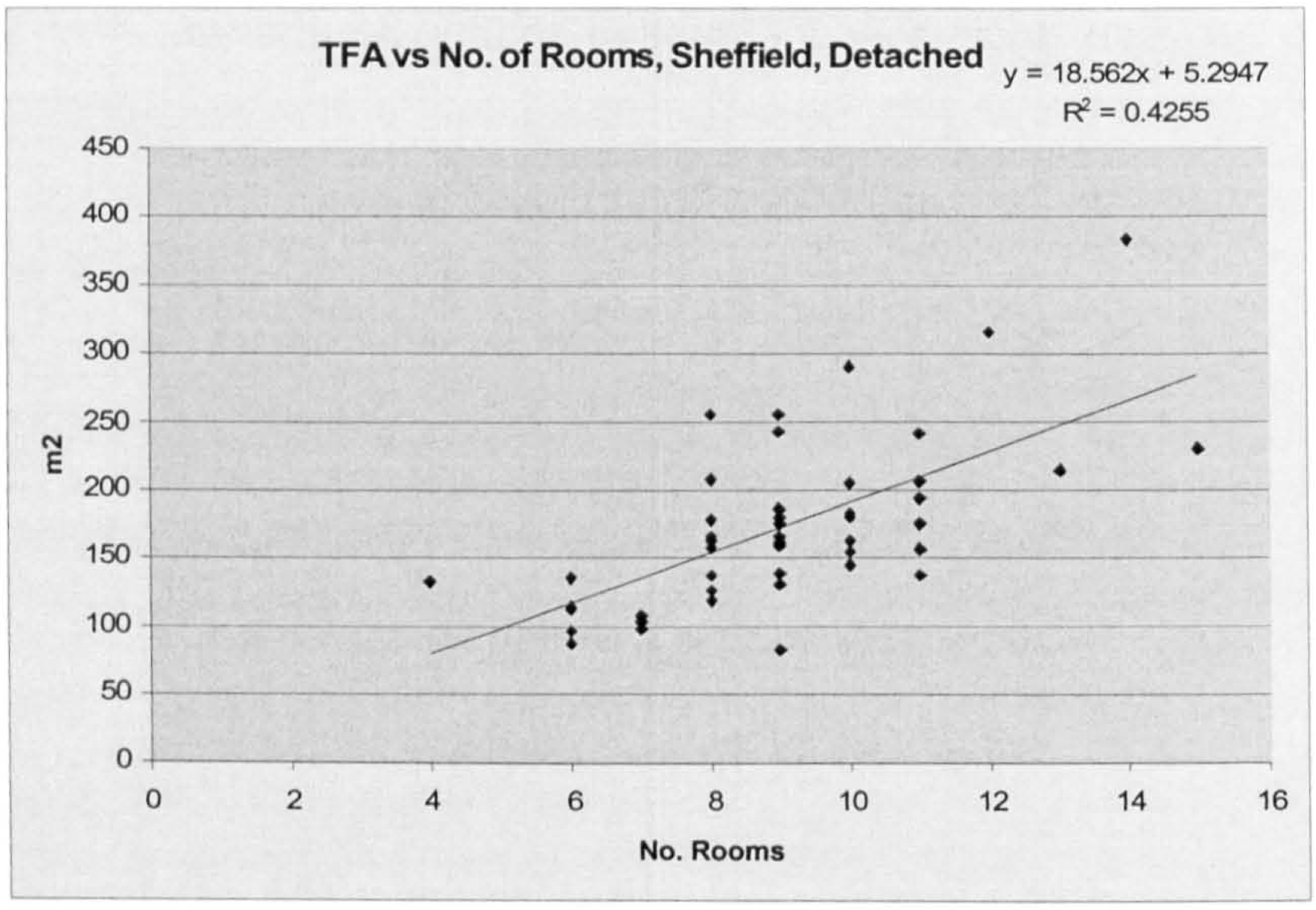


Figure 7.20. – TFA regressed against the number of rooms, Sheffield detached

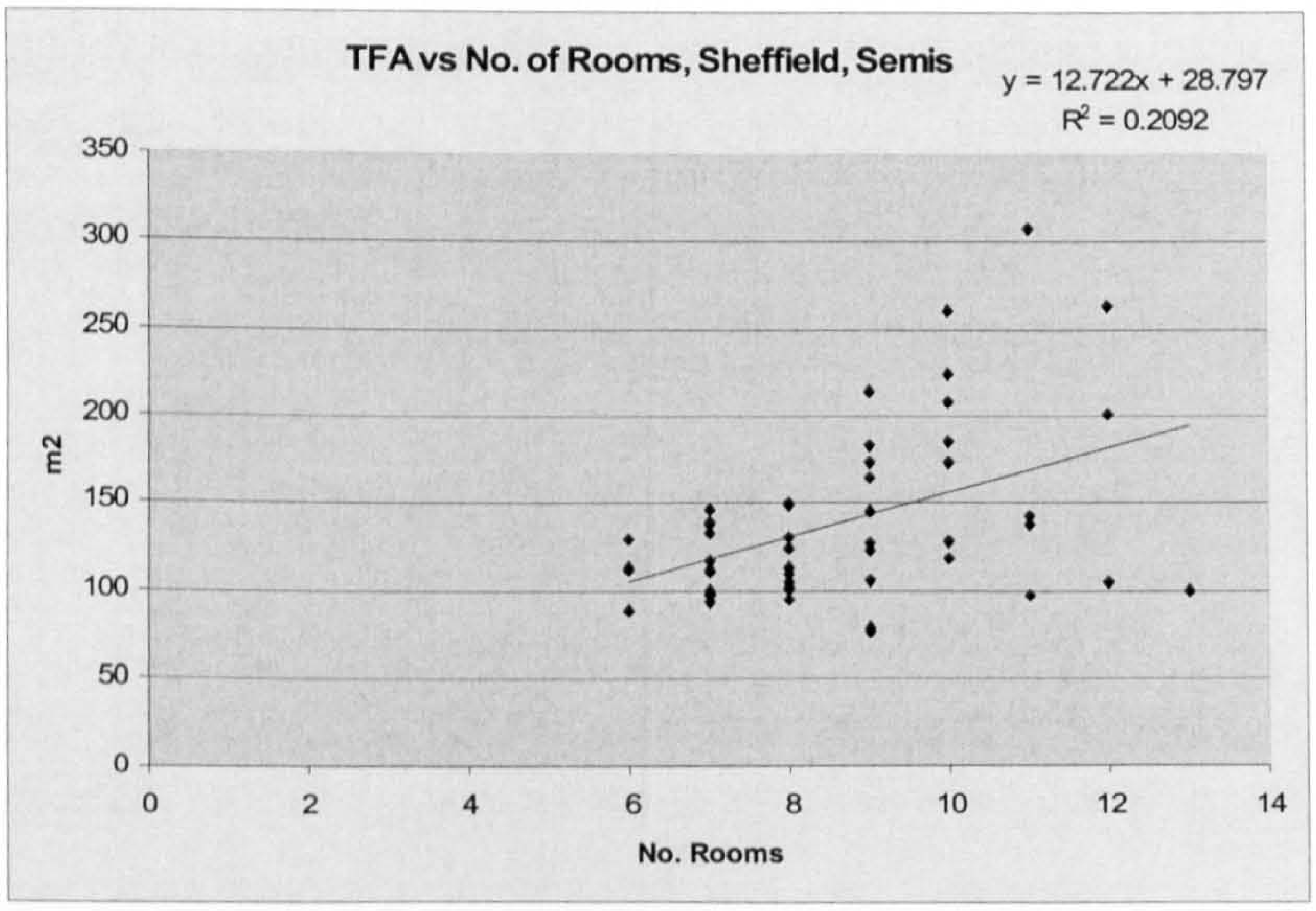


Figure 7.21. – TFA regressed against the number of rooms, Sheffield semis

These three plots are important in that they provide a strong indication of the level of variation in the internal make up of the dwellings that would otherwise be unreasonable to infer without requesting written descriptions or sketch plans from respondents.

Both the Leicester and Sheffield detached plots show clear relationships between TFA and the number of rooms, with relatively distinct and consistent variations. The variation is much more pronounced for the Sheffield semis and this may help explain the poorer correlations between gas consumption (the majority of which is assumed to be used for space heating) and TFA for this group. Although some caution is appropriate in interpreting these results as respondents may sometime have been unsure how to count distinct rooms, despite the clear questionnaire guidance notes.

No local knowledge was available on the general internal layout of dwellings in Sheffield, but both here and for Leicester the level of scatter may be consistent with a significant degree of home alteration. In the case of the Leicester terraces, for which a considerable local knowledge was available, the grounds for accepting the high correlation are strengthened by the plot of TFA against the number of bedrooms (Figure 7.22).

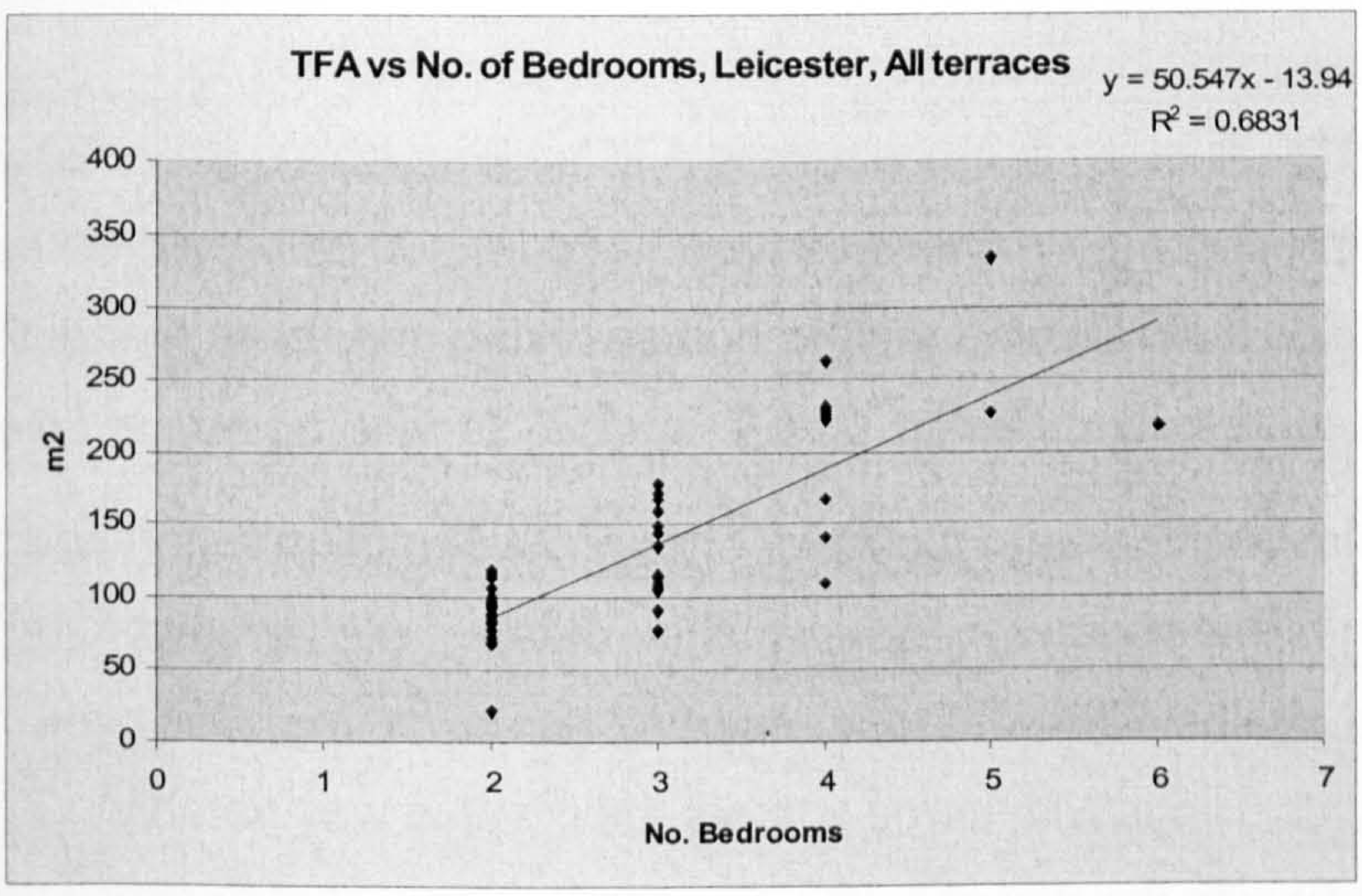


Figure 7.22. TFA regressed against the number of bedrooms, Leicester terraces

Despite the limited variation in the number of rooms and a concentration of dwellings with TFA <200m^2 this plot seems to confirm local knowledge. The study area is known to comprise a large group of the traditional terraces that are typical of Leicester as a whole, and a smaller group of larger terraces of similar age and construction. Three common modifications known to be made to these properties are the creation of an additional bedroom by splitting other rooms (common in rented properties); the creation of a larger main bedroom by incorporating another room; and the creation of open-plan living areas by wholly or partially removing internal walls on the ground floor. The clear and consistent variation in these two plots appears consistent with the existence of such modifications and gives further confidence in the reliability of the data. The lack of strong correlations between energy consumption and the number of rooms or bedrooms is unsurprising given that these changes are unlikely to have altered the number of radiators in use in these dwellings, all but three of which were reported as being heated by gas fuelled radiator systems.

For all three study areas TFA and energy consumption was also regressed against persons per bedroom (ppb, used as an indicator of population density – see Walker et al, 2001) but none of these produced an r^2 value above 0.16.

7.6. Homeworking

A final set of simple regression analyses was carried out to differentiate between those households that reported regular homeworking and those that did not - this produced three interesting results.

No significant relationships were found for energy consumption regressed against TFA for the non-homeworkers in the combined dataset, nor for electricity consumption regressed against TFA for those reporting homeworking. However, for gas consumption by dwellings with homeworkers the r^2 value was notably high at 0.4781 (p-value 0) with the plot showing an acceptable level of scatter (Figure 7.23).

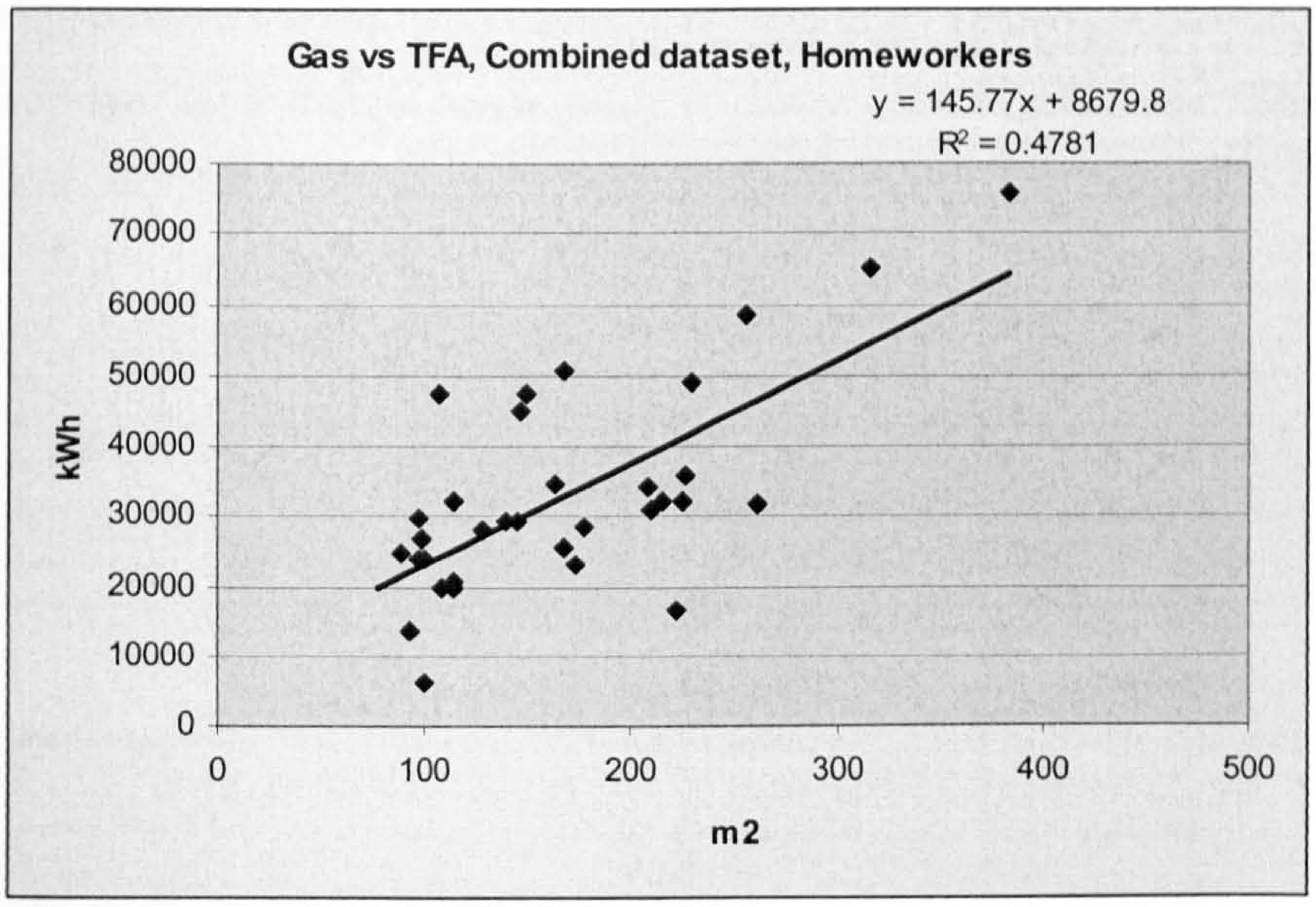


Figure 7.23. Gas consumption regressed against TFA, combined dataset, homeworkers

For the Leicester respondents reporting no homeworkers the regression of gas consumption against TFA produced an r^2 value of 0.2098, p-value 0.016, with no obvious distortions. For the households living in the detached dwellings in Sheffield that reported homeworkers the r^2 value was 0.7939, p-value 0, but this was based on only 12 records. Visual inspection revealed an obvious correlation, although perhaps not as high as suggested (Figure 7.24). The r^2 value for electricity against TFA for this group was 0.3127, but the p-value of 0.074 reflects the observed degree of scatter.

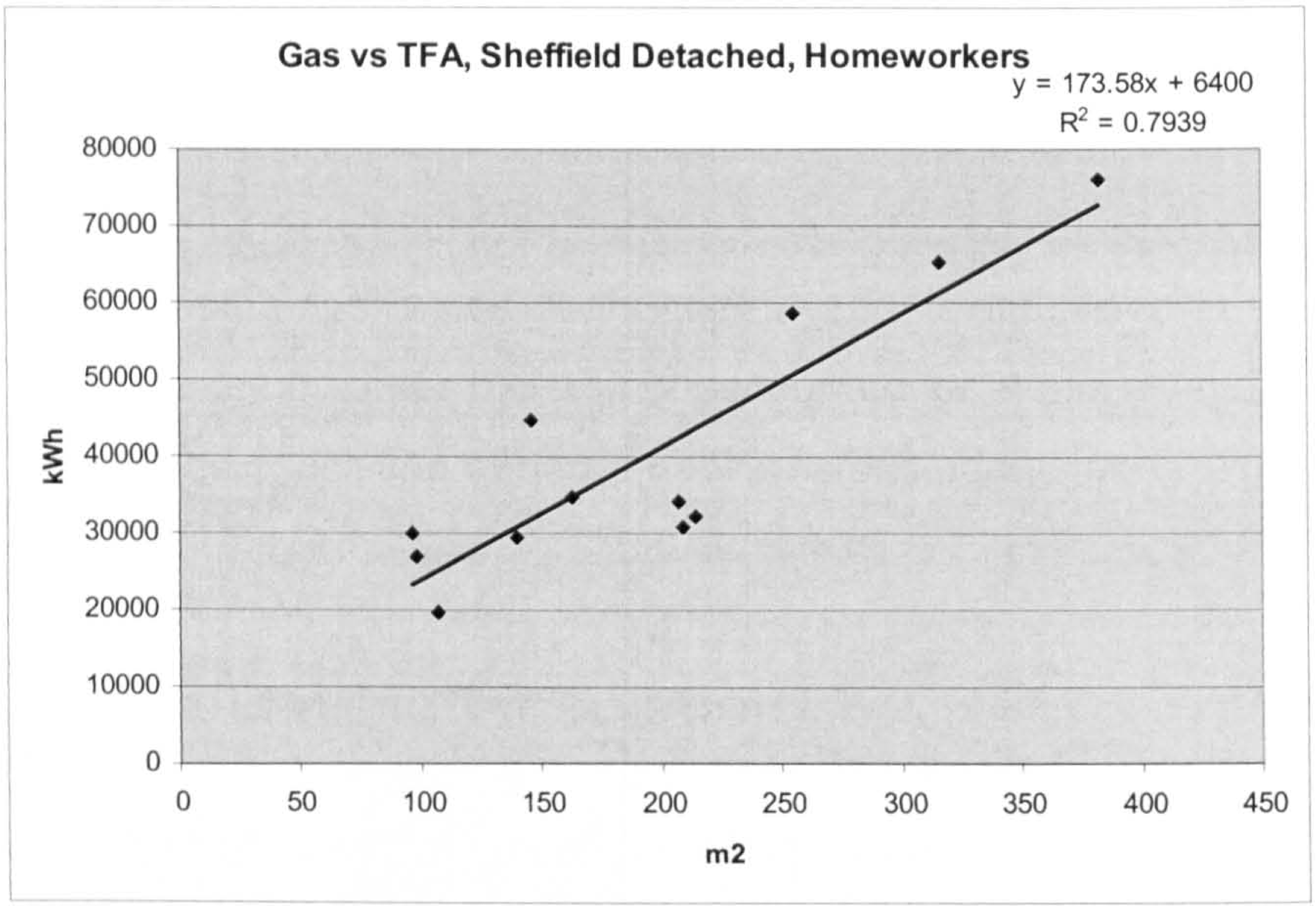


Figure 7.24. Gas consumption regressed against TFA, Sheffield detached, homeworkers

The remaining plots all produced low r^2 values. The lack of any strong relationships electricity consumption in these regressions was not as expected given that homeworkers should be expected to consume more electricity as a result of using appliances during the day. If this difference exists it may have been masked by other factors not accounted for at this level of analysis, such as households consisting of part-time workers, students and retired persons.

7.7. Wall and loft insulation

No notable relationships would be found between electricity consumption and TFA when the combined dataset was categorised by wall insulation type. This was unexpected as improved insulation is known to improve dwelling energy efficiency (section 2.2.1). The strongest relationship was found in the solid wall group (r^2 value 0.1864, p-value 0.006) with r^2 values of 0.1103 and 0.0023 for the cavity and filled cavity categories respectively, with all three plots showing clear scatter.

For gas consumption regressed against TFA the relationship was insignificant for the filled cavity walls group (r^2 value 0.0863) however this was stronger for the solid walls group (r^2 value 0.2454, p-value 0.009, Figure 7.25) and strongest for the cavity walls group (r^2 value 0.4617, p-value 0, Figure 7.26) with the lower levels of scatter indicating that these values were representative of the distributions.

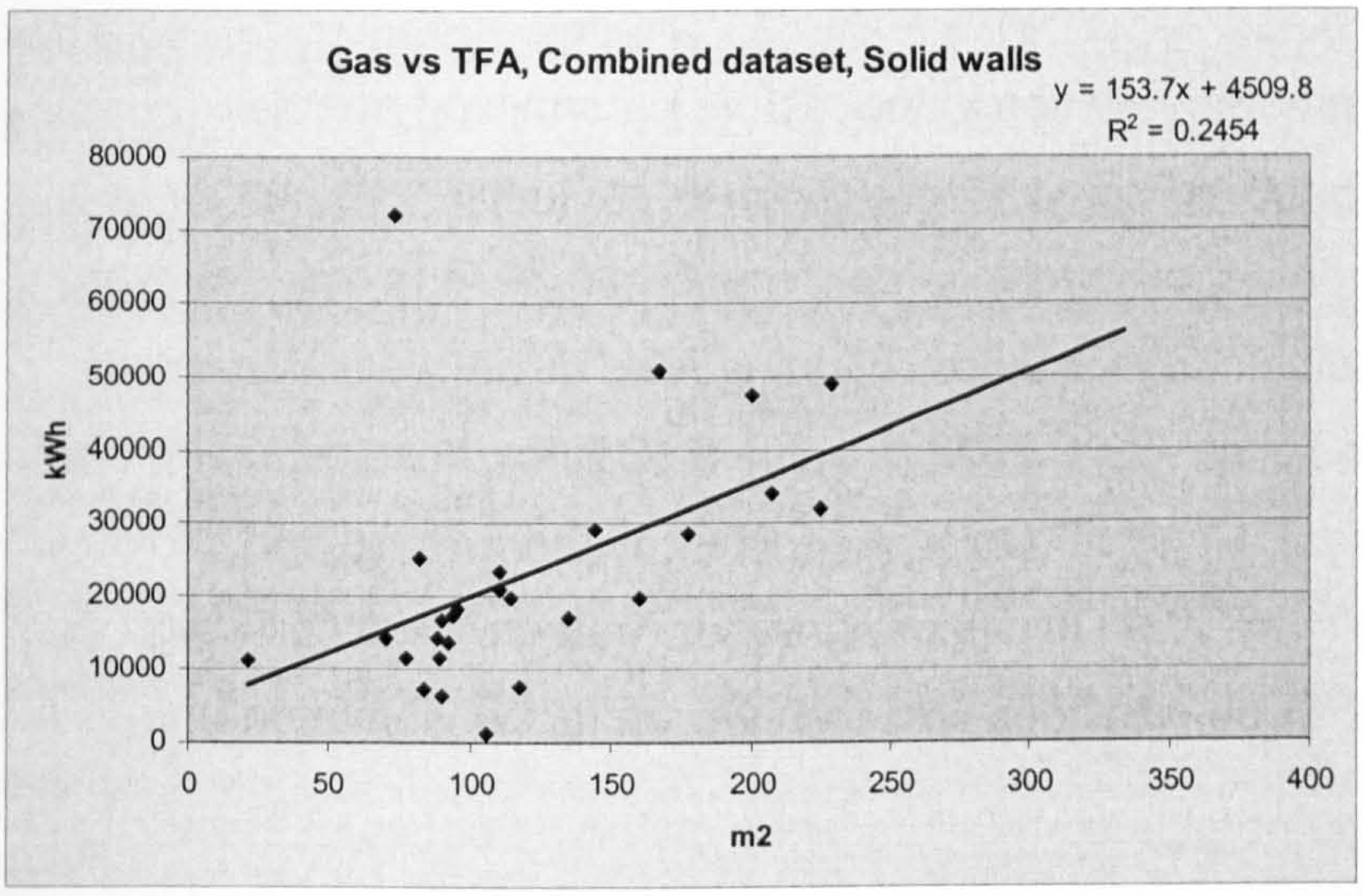


Figure 7.25. Gas consumption regressed against TFA, combined dataset, solid walls

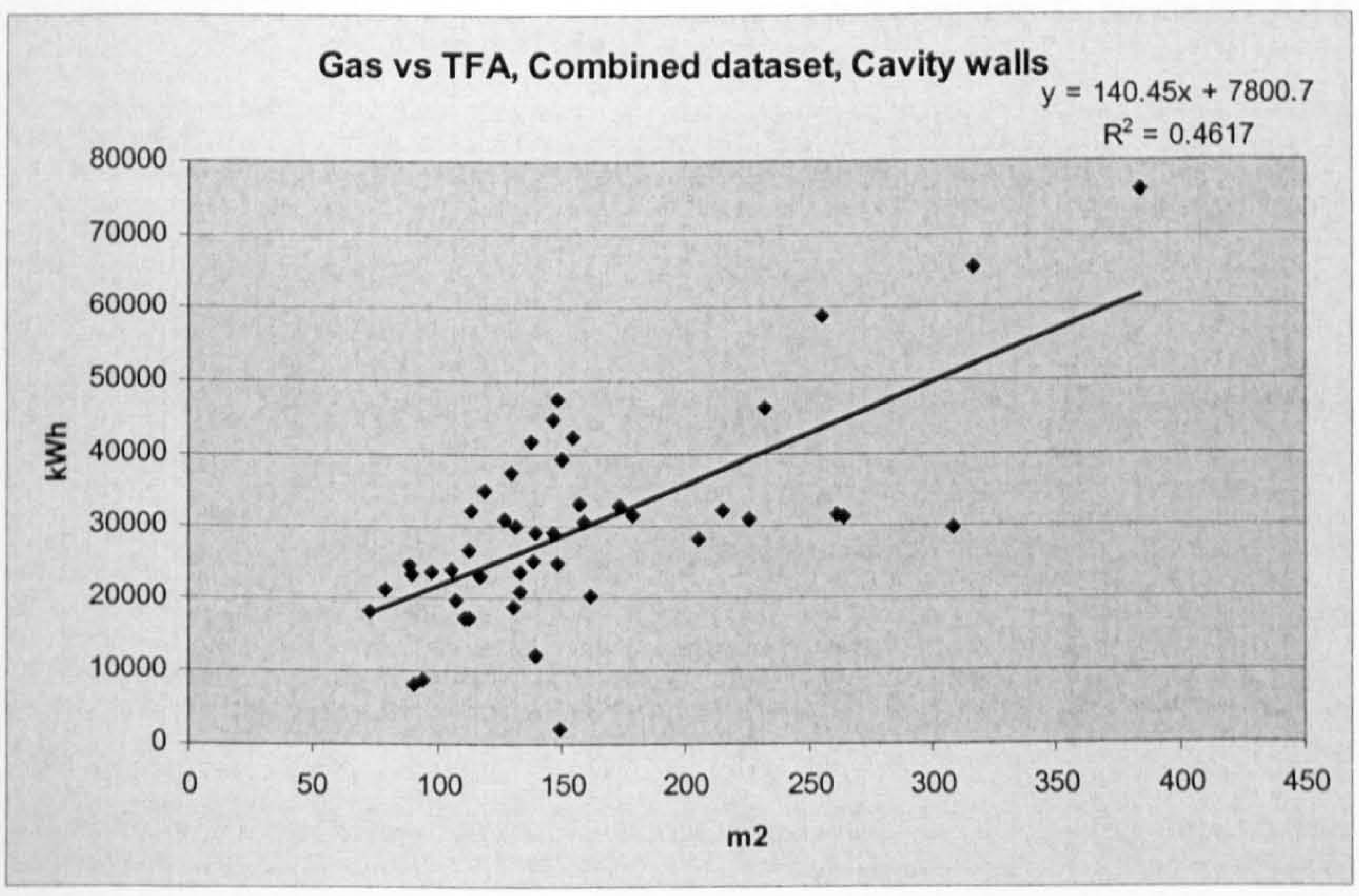


Figure 7.26. Gas consumption regressed against TFA, combined dataset, cavity walls

The Leicester dataset contained only a small group of dwellings reported as having cavity or filled cavity walls so these were grouped together for the regression. No solid walls were reported for the Sheffield dwellings and the datasets of detached and semi-detached dwellings were separated into two roughly equal groups with filled cavity walls and unfilled cavity walls.

For the Leicester dwellings with solid walls the r^2 value for gas against TFA was 0.1652, p-value 0.054 (for 23 records).

Indications of greater variation in the factors determining energy consumption for the Sheffield semis were again evident in the r^2 values for gas against TFA. For the detached dwellings an r^2 value of 0.3074 (p-value 0) was calculated for gas against TFA for those reporting filled cavity walls, but most significantly the same figure was 0.7327 (p-value 0.401) for those reporting only cavity walls (18 records). However, as is suggested by the p-value and shown in the plot of the data (Figure 7.27) this figure is almost certainly artificially high due to being leveraged by three dwellings with high values for consumption and TFA.

As expected, no notable correlations were observed between electricity consumption and TFA for any of these sub-categories.

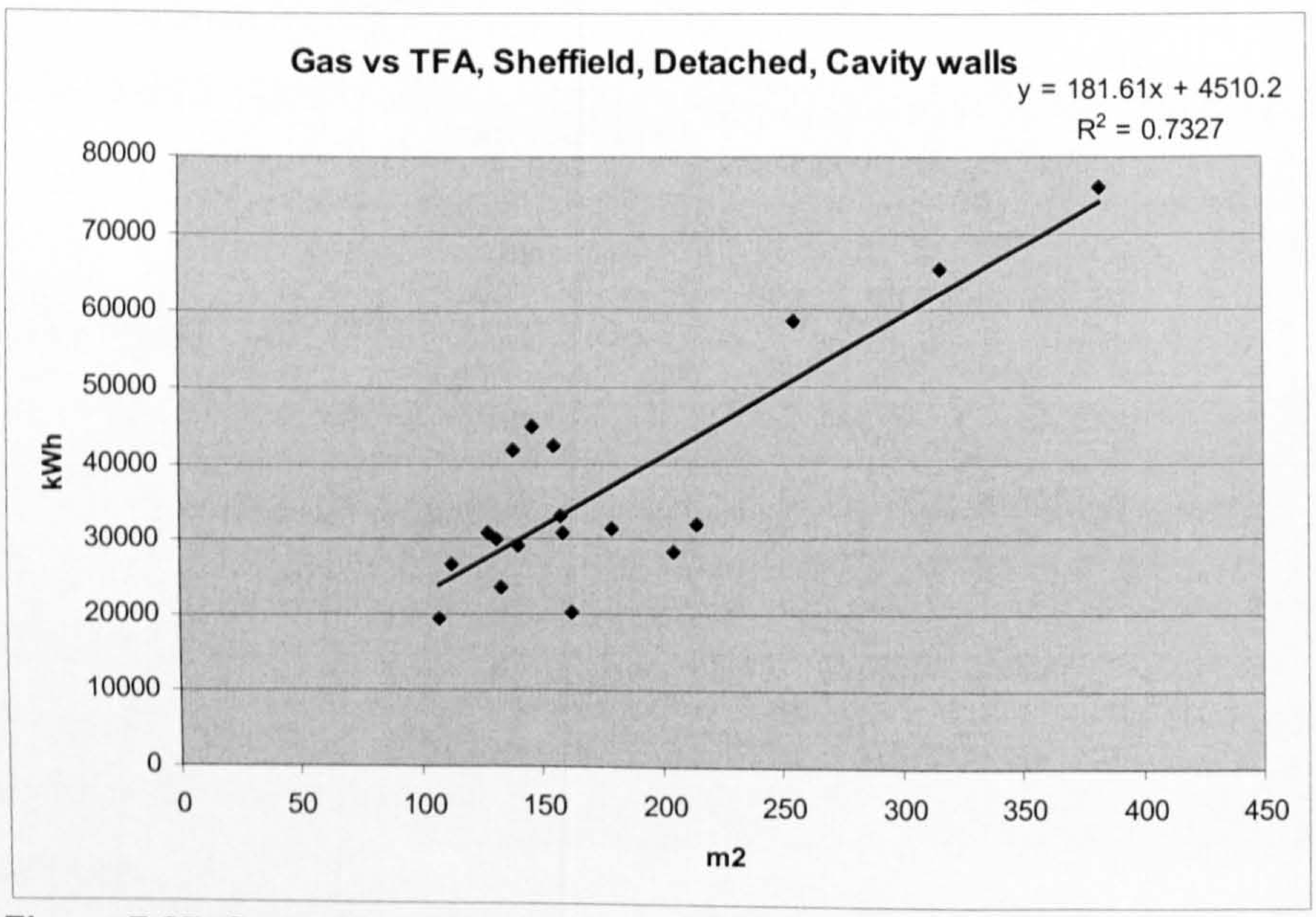


Figure 7.27. Gas consumption regressed against TFA, Sheffield detached, cavity walls

Loft insulation was another category for which it was possible to regress consumption and TFA directly against numerical values, however in this case it was suspected that respondents would be unlikely to report this accurately and none of the r^2 values were significant.

7.8. Boiler type

Installing a more efficient boiler is another improvement known to reduce dwelling energy consumption (section 2.2.1). For this variable the dataset respondents reported a mix of combi and/or condensing boilers, therefore the data was categorised by those reporting normal boilers and combi and/or condensing models in order to produce a category with sufficient numbers of records for the results to be meaningful.

As for insulation it was not expected that any notable relationships would be found between TFA and electricity consumption within each category, although an r^2 value of 0.2137 (p-value 0) was obtained for this regression for the normal boilers group. However, for gas consumption the two r^2 values were similar – 0.3770 and 0.3453 (both with p-values of 0) for the normal and combi/conventional groups respectively (Figures 7.28 and 7.29).

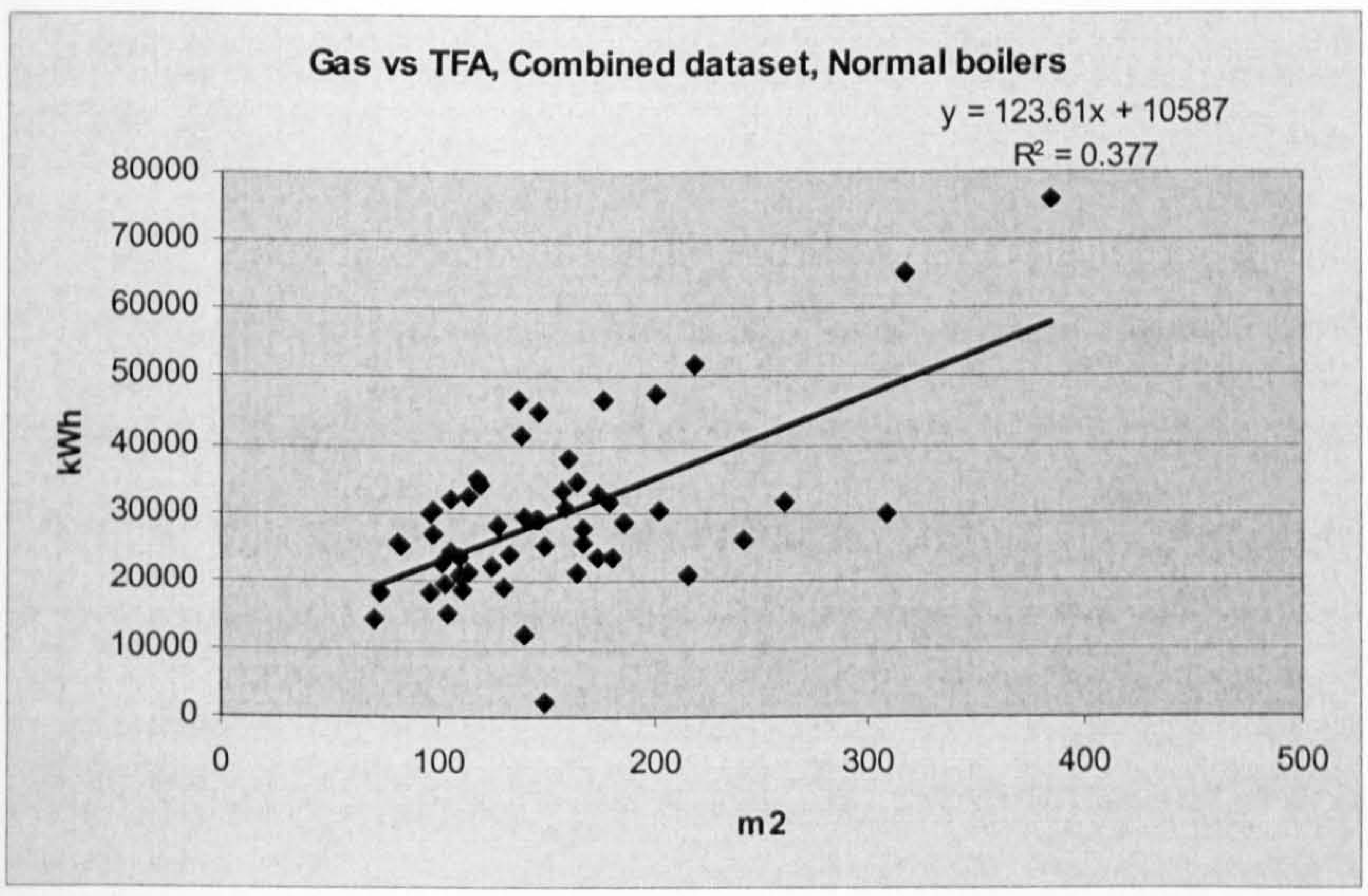


Figure 7.28. Gas consumption regressed against TFA, combined dataset, normal boilers

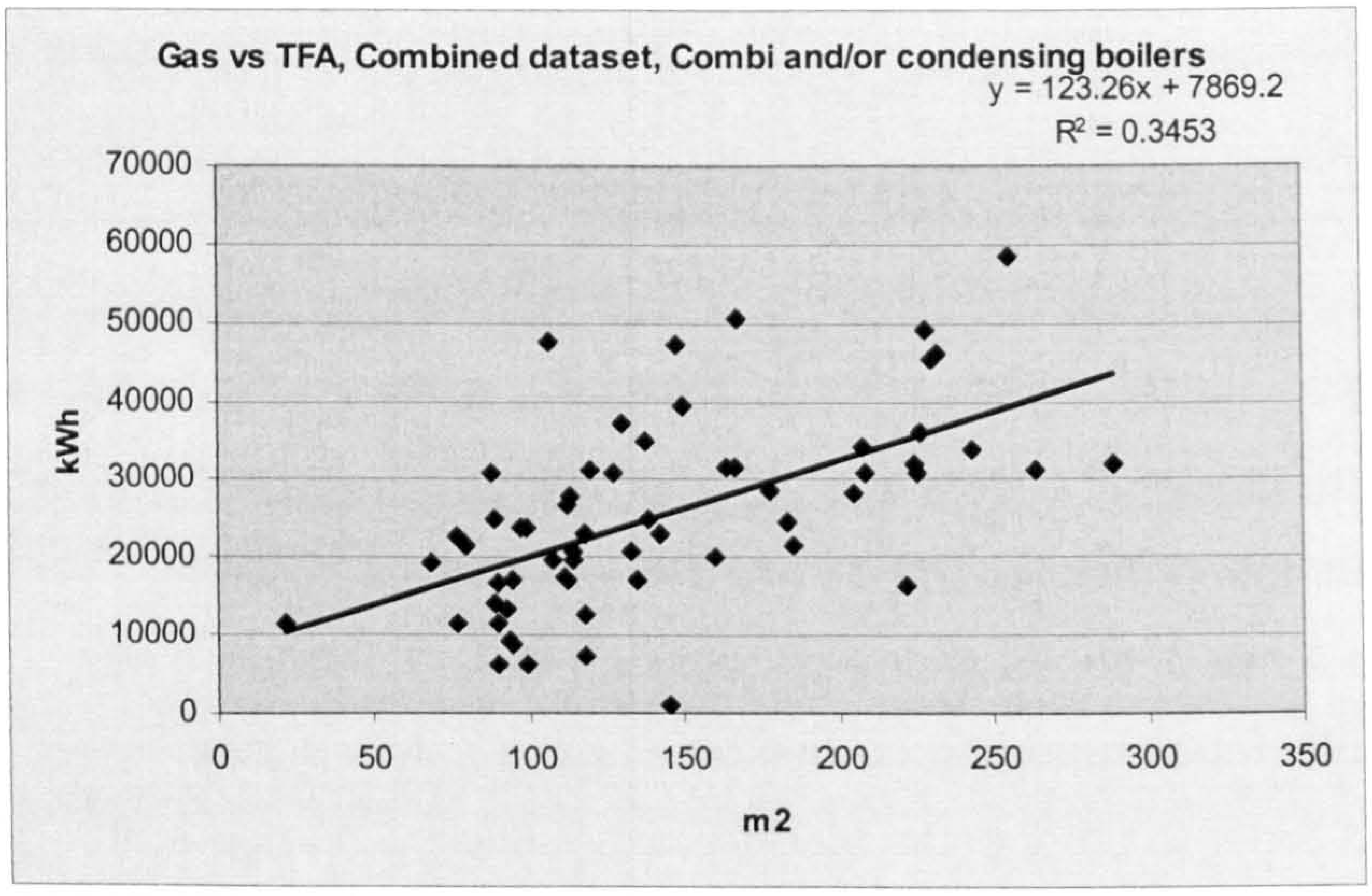


Figure 7.29. Gas consumption regressed against TFA, combined dataset, combi and/or condensing boilers

For the individual subsets an r^2 value of 0.7315 was obtained for gas consumption against TFA for the Leicester dwellings with normal boilers and 0.5282 for the Sheffield detached dwellings (Figures 7.30 and 7.31). Although the latter correlation appears to be leveraged by two larger, higher consuming dwellings the p-values were 0.003 and 0 respectively. In addition an r^2 value of 0.4082 (p-value 0.019) was calculated for electricity consumption against TFA for this sub-category of the Leicester dwellings. No other notable correlations were found.

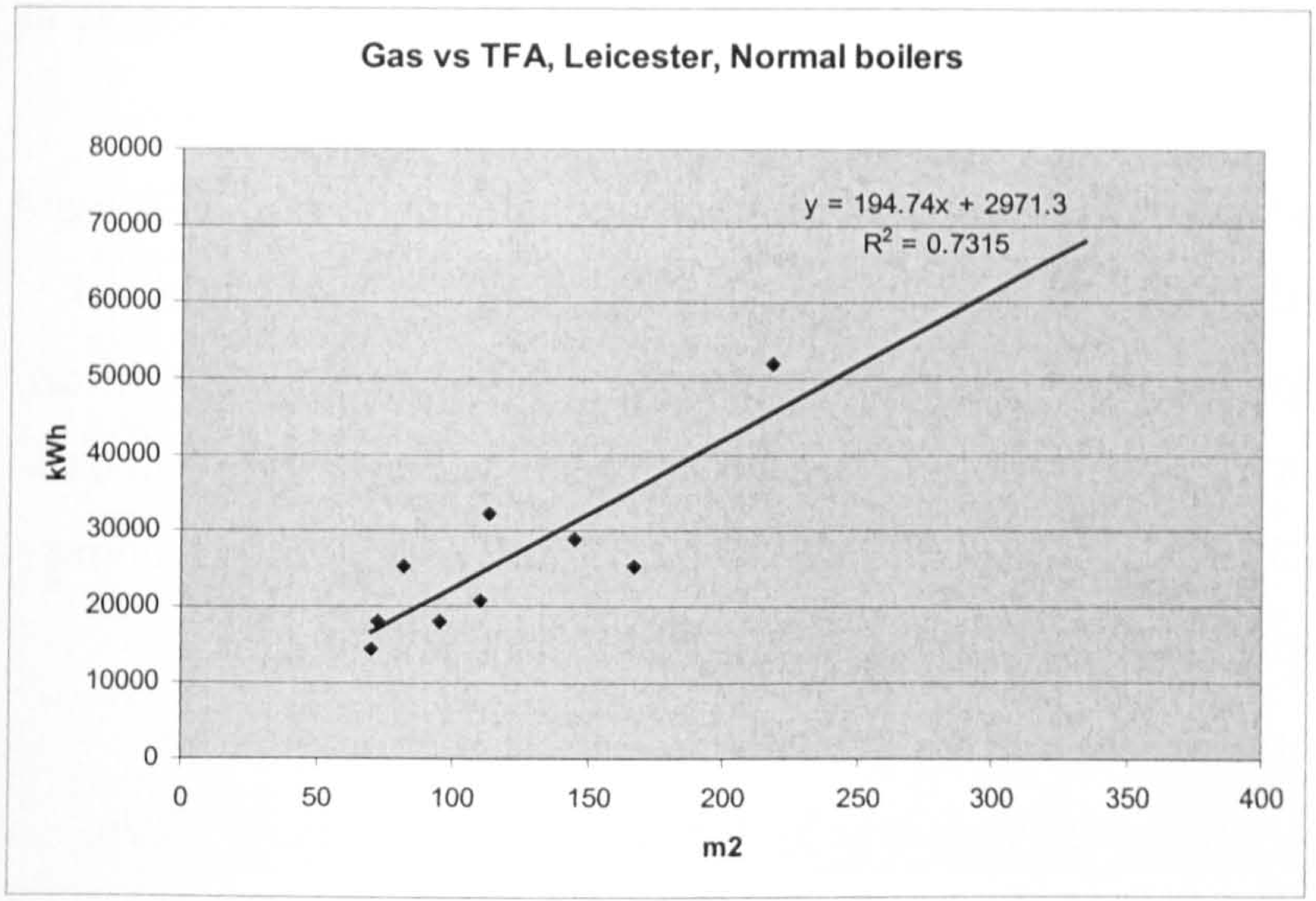


Figure 7.30. Gas consumption regressed against TFA, Leicester terraces, normal boilers

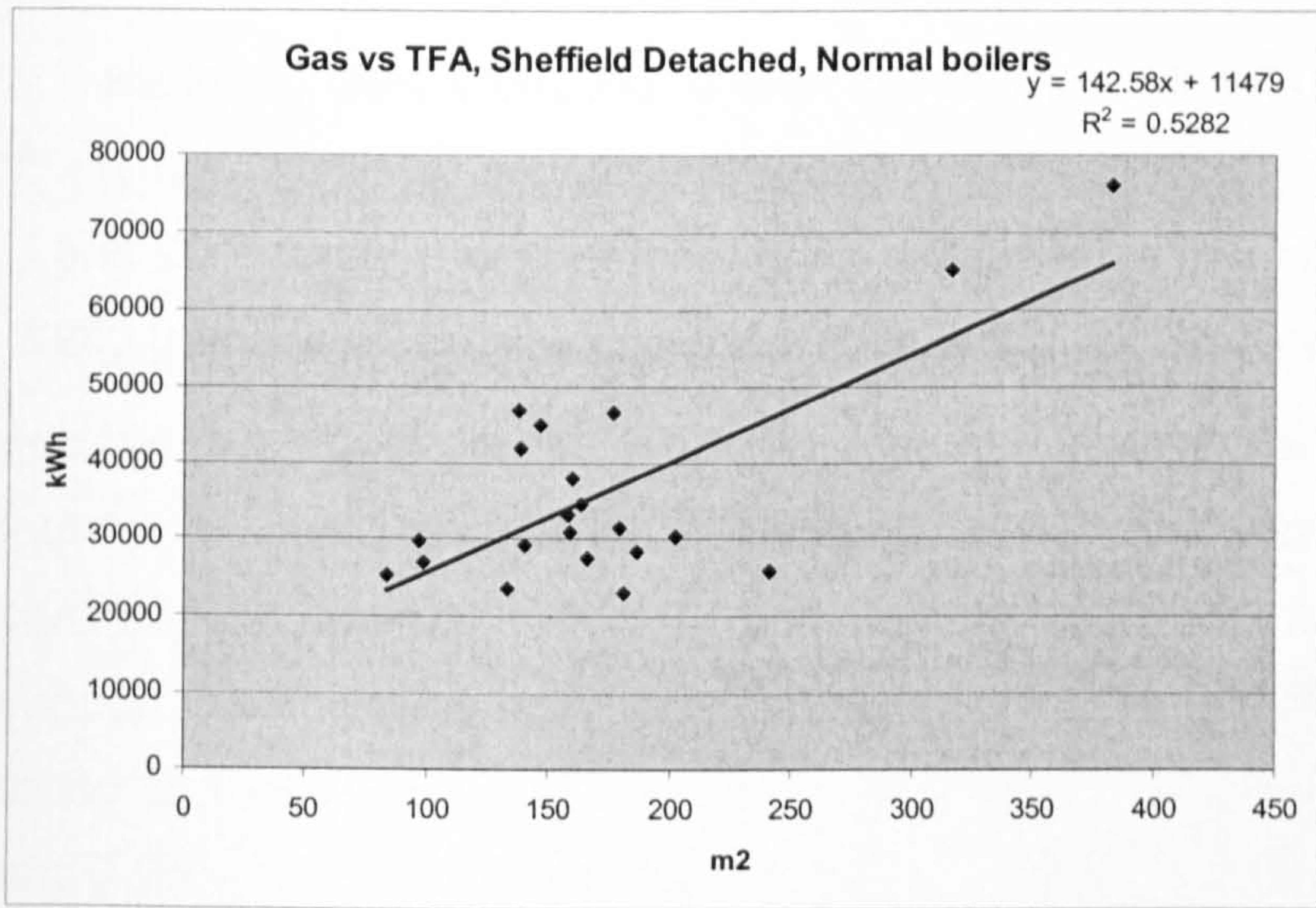


Figure 7.31. Gas consumption regressed against TFA, Sheffield detached, normal boilers

7.9. Thermostatic radiator valves

Given the knowledge that most of the dwellings with consumption data were heated by radiator systems (section 4.7.3) the merit of differentiating between those with and without TRVs was tested, with some good results. This was especially significant as for this variable adequate samples were available in all the subsets of data.

As before the relationships between electricity consumption and TFA were insignificant when the data was categorised by this variable. For the combined dataset the relationships between gas consumption and TFA were evident when the records were split into those reporting TRVs and those without, the r^2 values being 0.3639 and 0.2217 respectively (p-values both 0) however some stronger relationships were found within the three individual subsets.

Conversely, for the three subsets the r^2 values for gas consumption regressed against TFA were clearly weaker for those dwellings without TRVs. For the Leicester dwellings the r^2 value was insignificant (near-0) and for the Sheffield semis it was 0.1543, but for the detached properties the correlation was much stronger (r^2 value 0.48, p-value 0).

For those with TRVs the correlations were 0.514 and 0.5486 (p-values both 0) for the Leicester terraces and the Sheffield detached dwellings, with visual inspection showing an even scatter along the trendline (Figures 7.32 and 7.33). However, for the semis the r^2 value for this group was insignificant (0.0392, p-value 0.313).

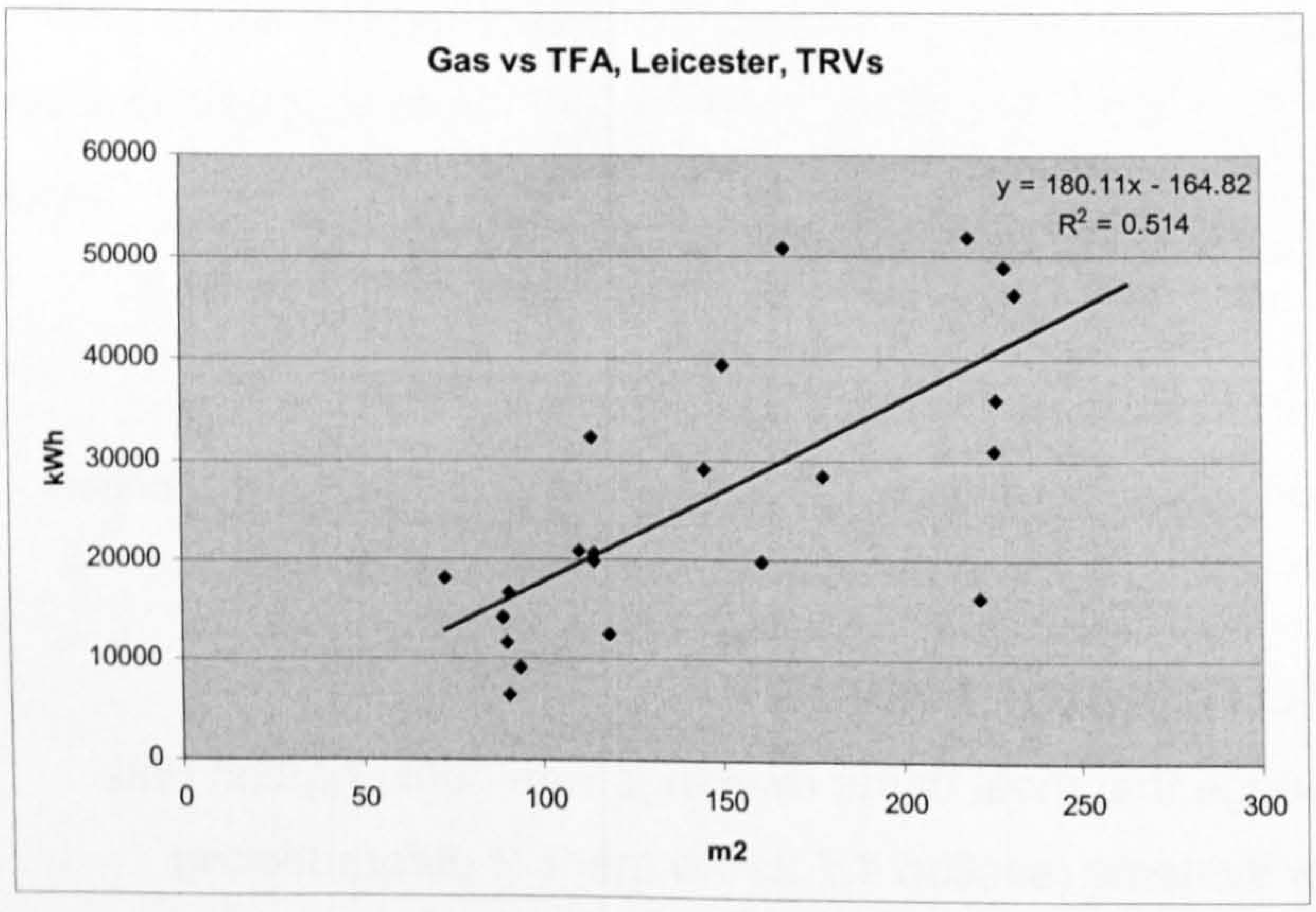


Figure 7.32. Gas consumption regressed against TFA, Leicester terraces, TRVs

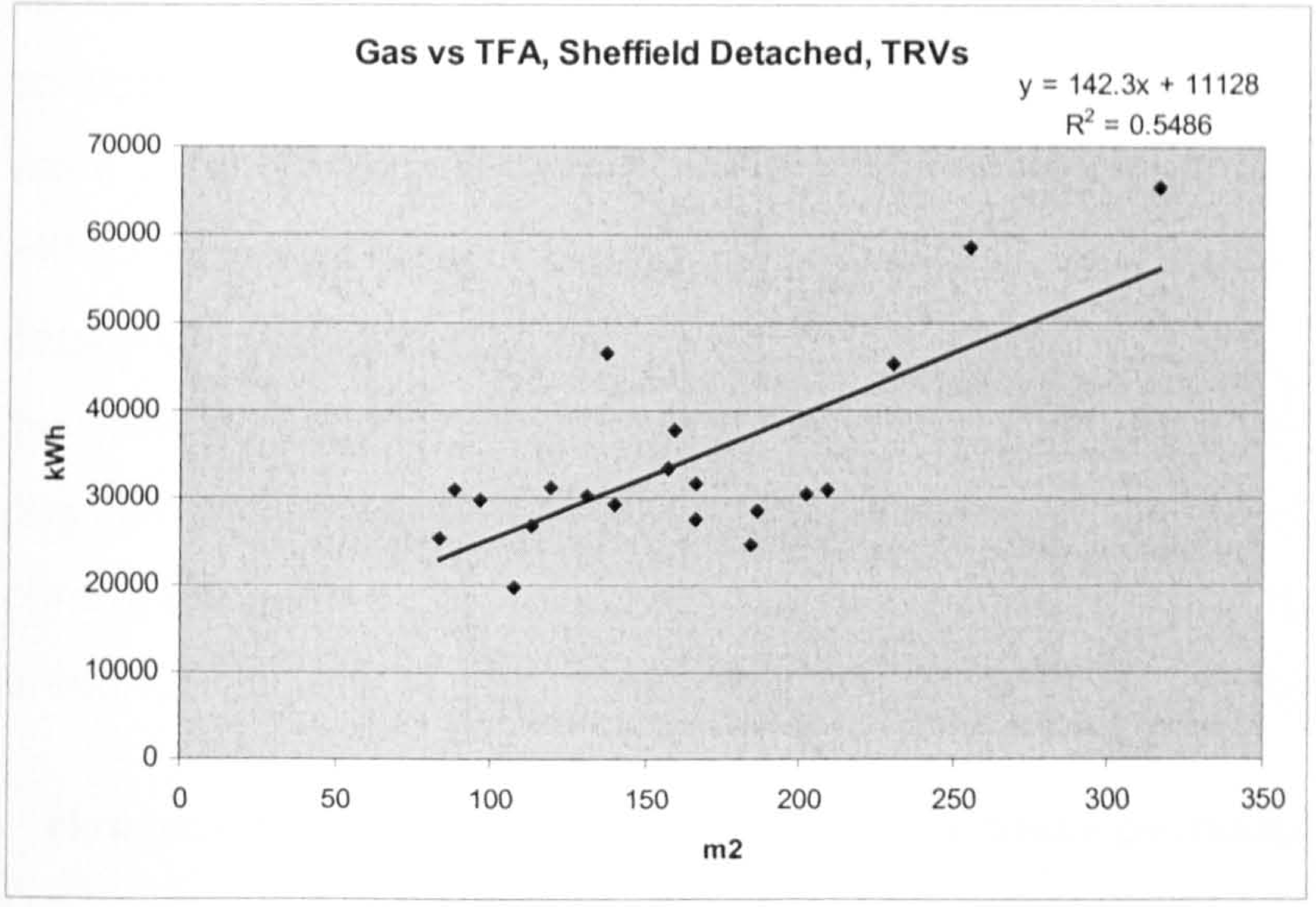


Figure 7.33. Gas consumption regressed against TFA, Sheffield detached, TRVs

7.10. Mechanical and digital heating system controls

In theory dwellings fitted with digital heating system controls should allow occupants a higher degree of control over their level of thermal comfort than those with simple mechanical clock/timer controls. The regressions of gas consumption against TFA for the combined dataset split into these categories support this assertion, with r^2 values of 0.4575 and 0.2716 (p-values both 0) found for those with digital and mechanical controls respectively (Figures 7.34 and 7.35).

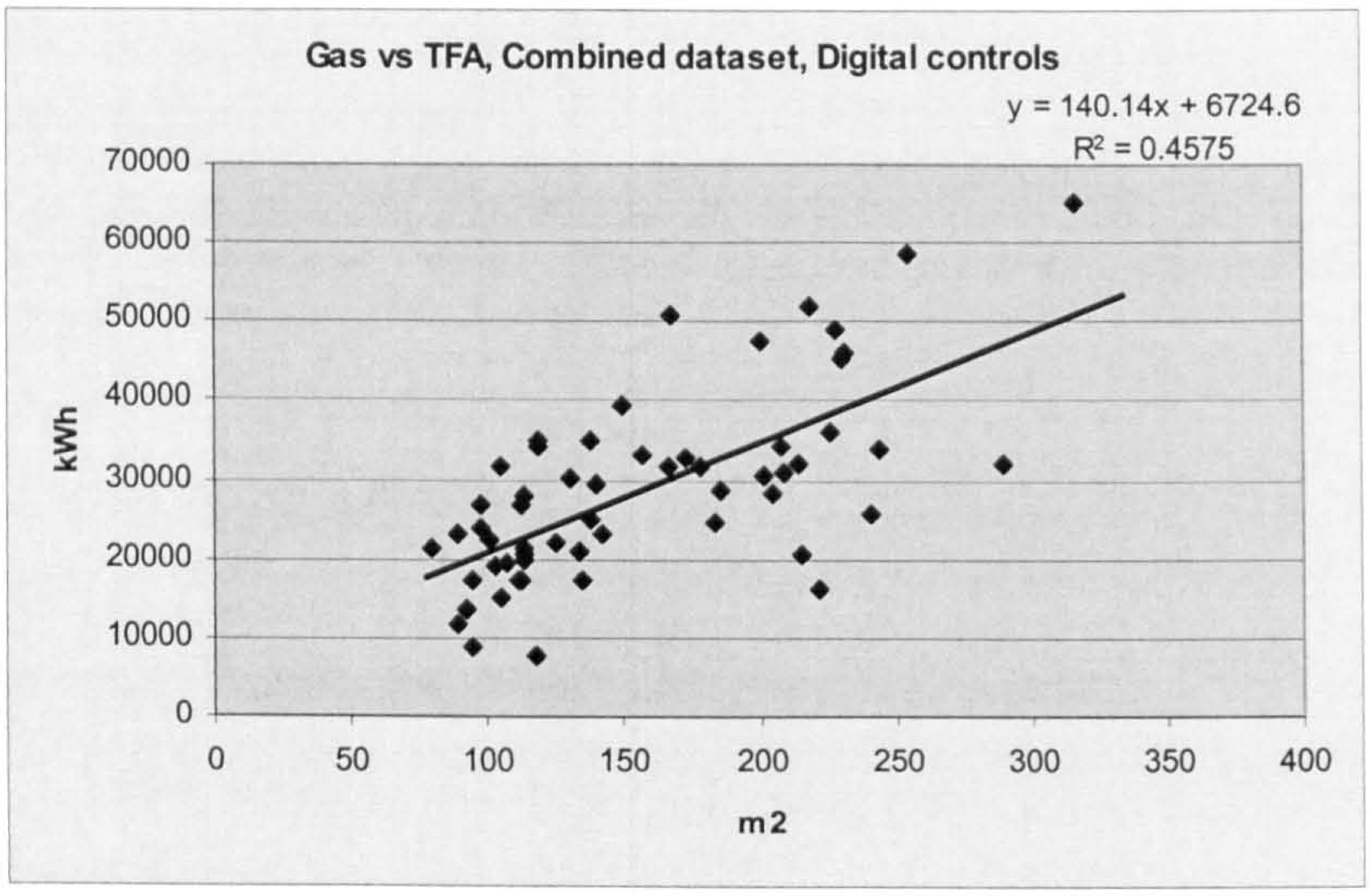


Figure 7.34. Gas consumption regressed against TFA, combined dataset, digital controls

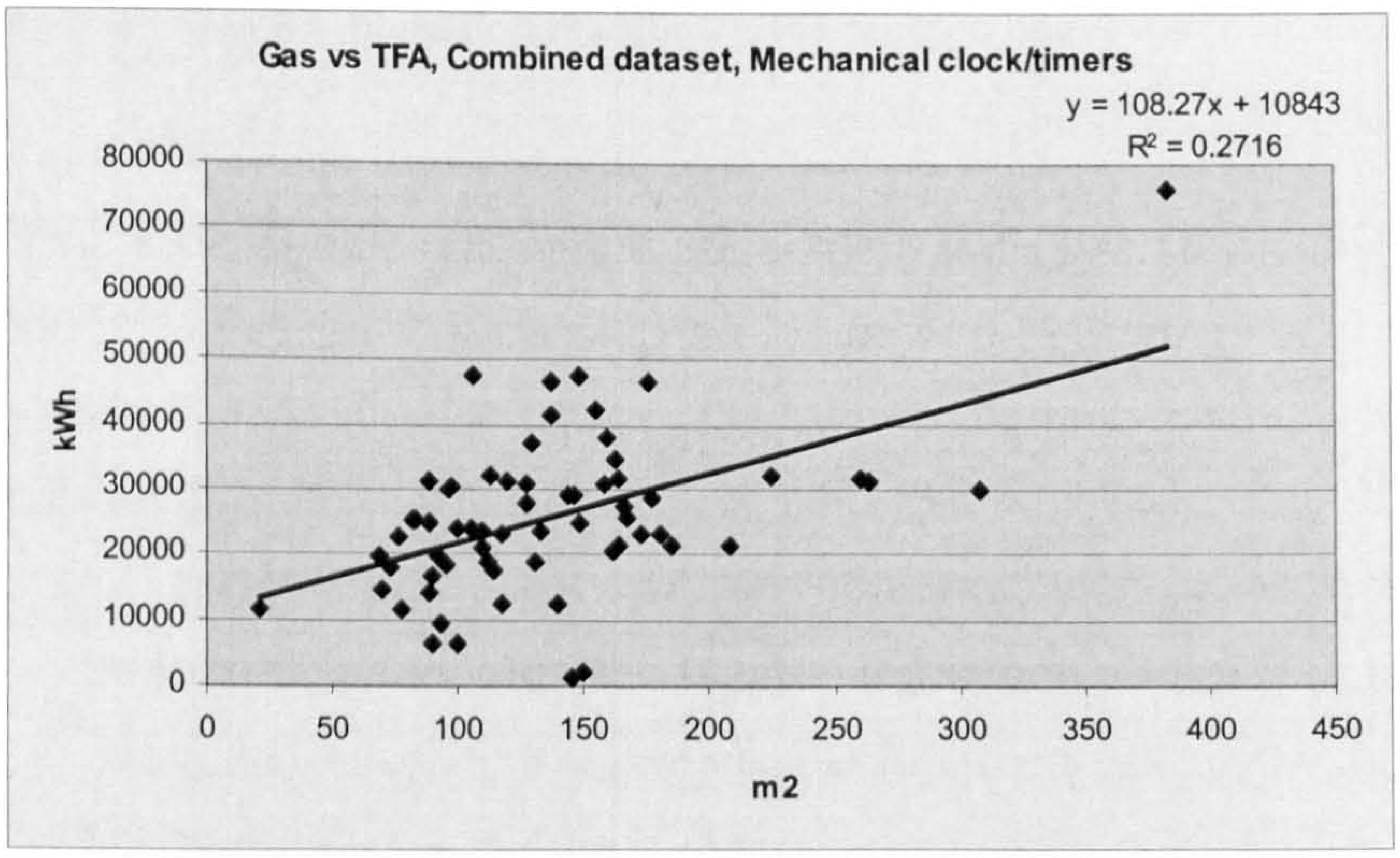


Figure 7.35. Gas consumption regressed against TFA, combined dataset, mechanical clock/timers

When the dataset was separated into those households who reported controlling their heating by mechanical timers and those who reported digital controls a similar pattern was observed as with the TRV regressions. The group of semis in Sheffield again produced plots with a relatively high level of scatter and no significant r^2 values. The r^2 value of 0.5721 (p-value 0) obtained for the detached dwellings with mechanical timers for gas consumption regressed against TFA also appears unrepresentatively high due to leverage by a cluster of points at one end of the scale. However, the r^2 values obtained for gas consumption regressed against TFA for both the Leicester sub-groups (0.525, p-value 0, for dwellings with digital controls and 0.2137, p-value 0.040, for those with mechanical timers) and the value of 0.4372 (p-value 0) for group of detached dwellings in Sheffield with digital controls seemed more consistent with the observed scatter (Figures 7.36, 7.37 and 7.38). This served to highlight one possible area for further investigation: whether or not the additional level of control provided by digital timers has any significant impact where TRVs are present.

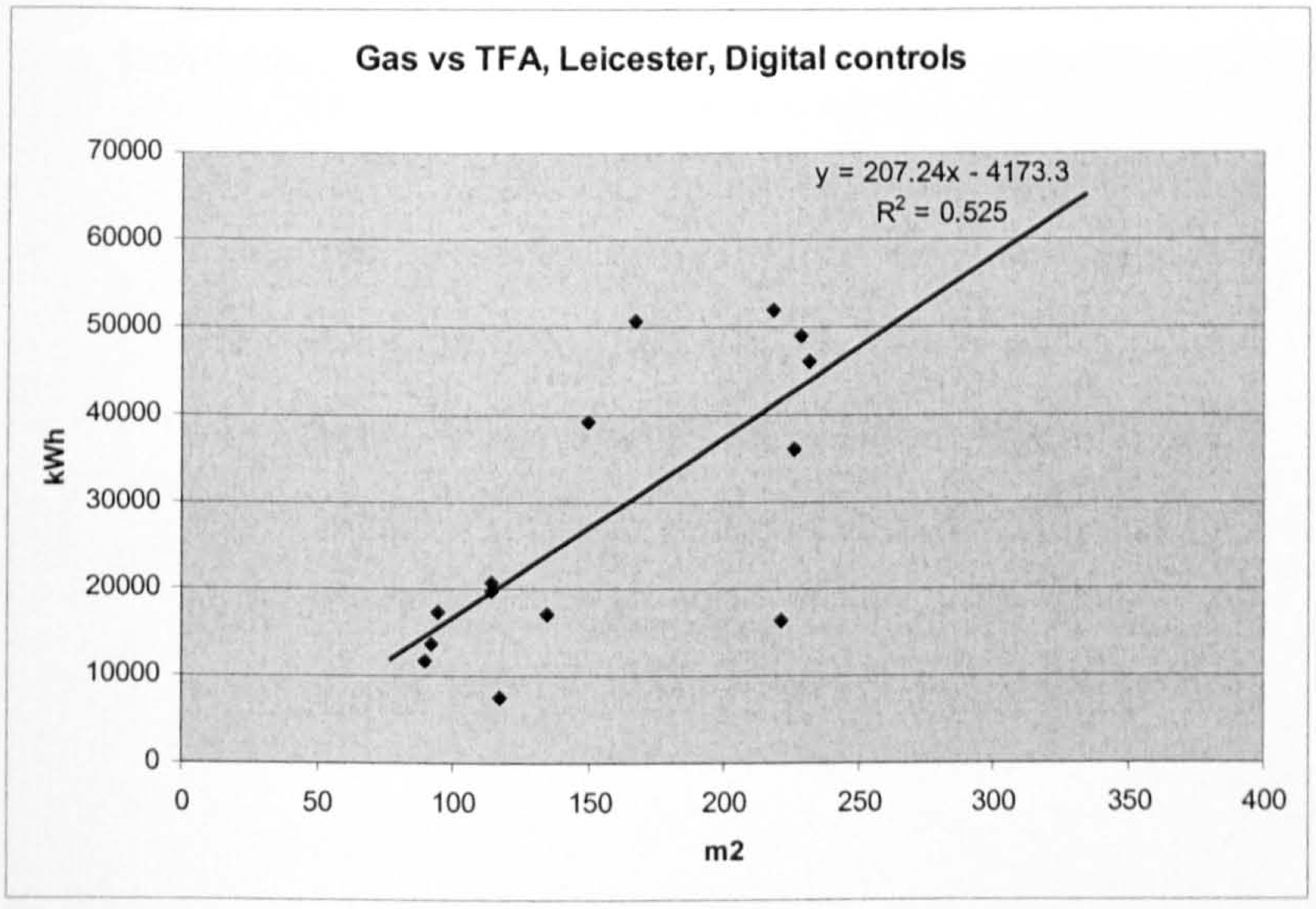


Figure 7.36. Gas consumption regressed against TFA, Leicester terraces, digital controls

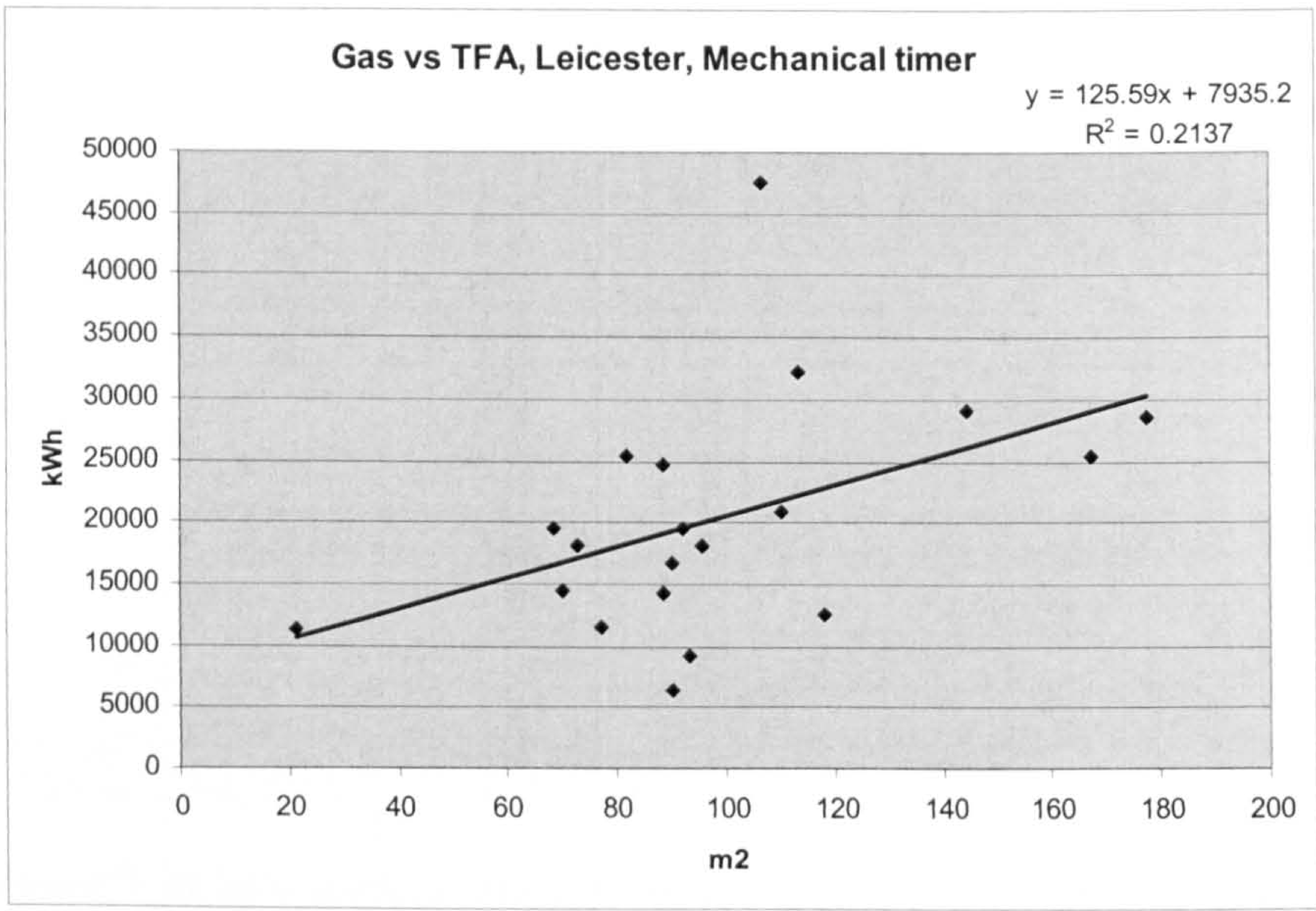


Figure 7.37. Gas consumption regressed against TFA, Leicester terraces, mechanical clock/timers

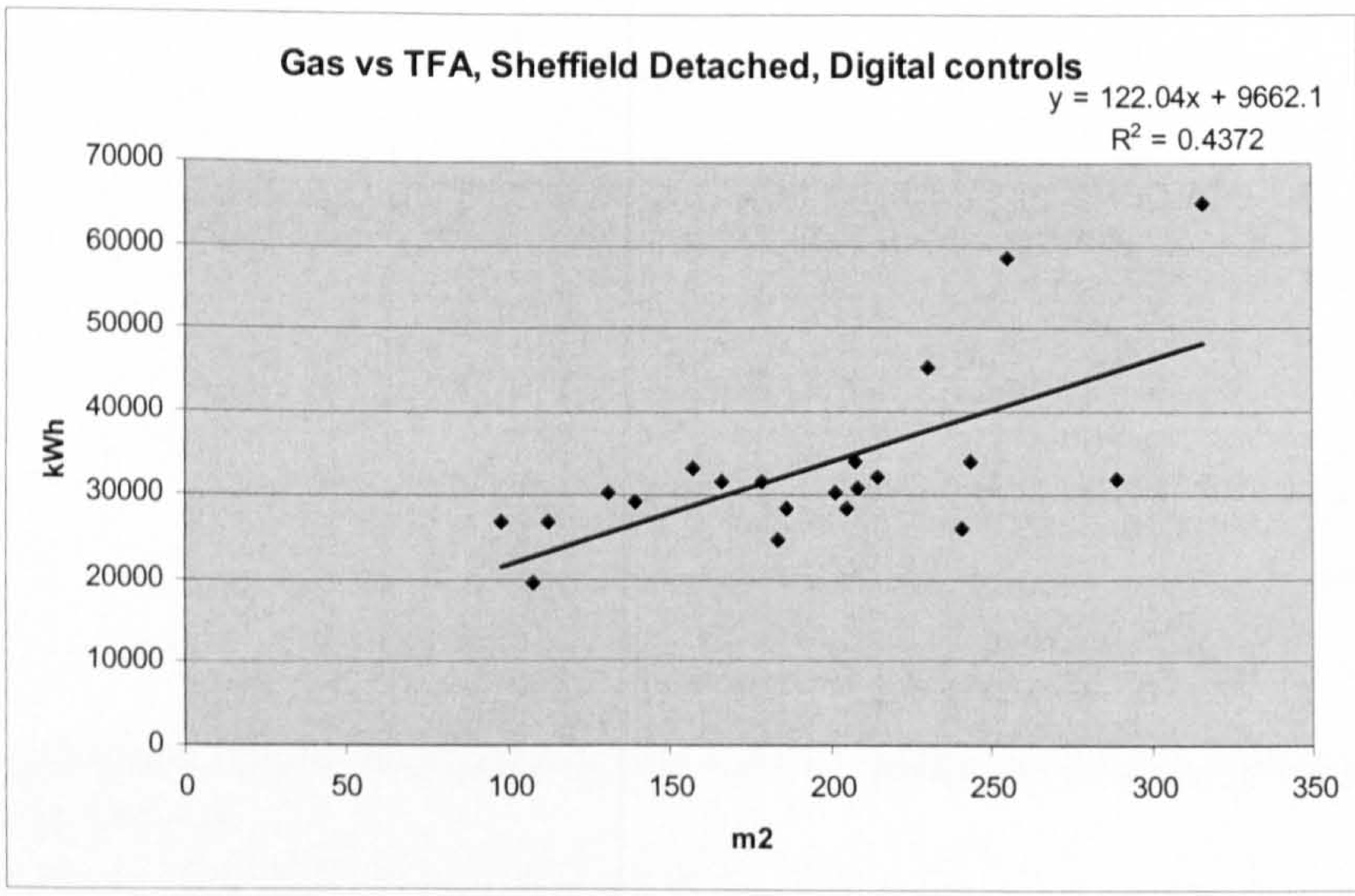


Figure 7.38. Gas consumption regressed against TFA, Sheffield detached, digital controls

7.11. Gas ducted warm air systems

A group of respondents from the detached dwellings in Sheffield reported gas ducted warm air systems as their main form of space heating. For these dwellings 9 were matched with electricity and 10 with gas consumption data, however plotting these values against TFA failed to produce any significant correlations.

7.12. Thermostats and settings

When the dwellings were split into those with and without thermostats the relationships between gas consumption and TFA were again stronger for those with thermostats than those without, providing further evidence for occupants with thermostats exerting a greater degree of control over their levels of thermal comfort. For the combined dataset the r^2 values for these relationships were 0.3399 (p-value 0, Figure 7.39) for those with thermostats and 0.2375 (p-value 0.001) for those without.

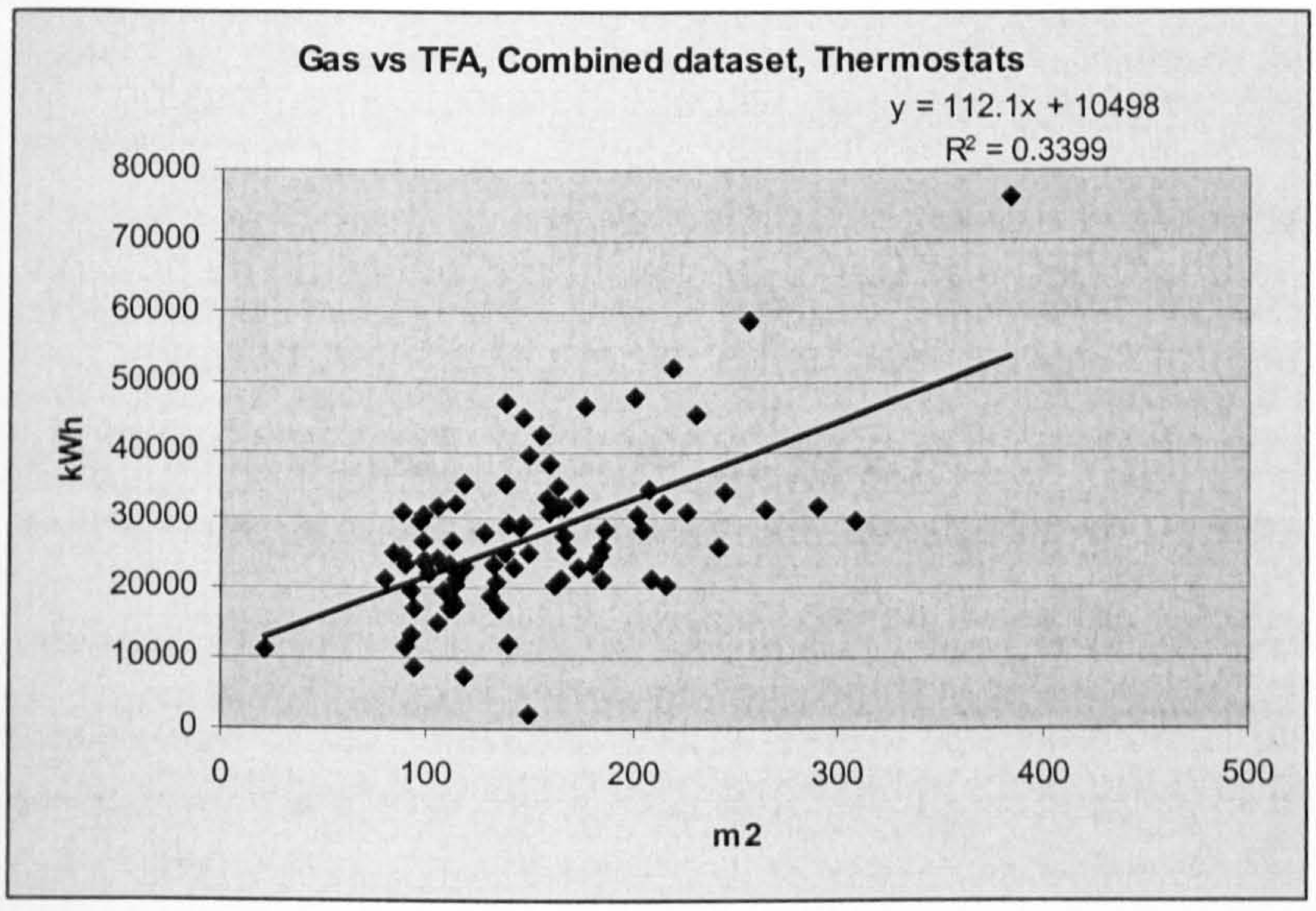


Figure 7.39. Gas consumption regressed against TFA, combined dataset, thermostats

For the Leicester dwellings the plot of gas against TFA for those dwellings without thermostats returned an r^2 value 0.1628. For the 10 records for the gas consumption of dwellings with thermostats regression against TFA gave an r^2 value of 0.7012 (p-value 0.002) and visual inspection revealed a plot with points evenly distributed along the trendline (Figure 7.40).

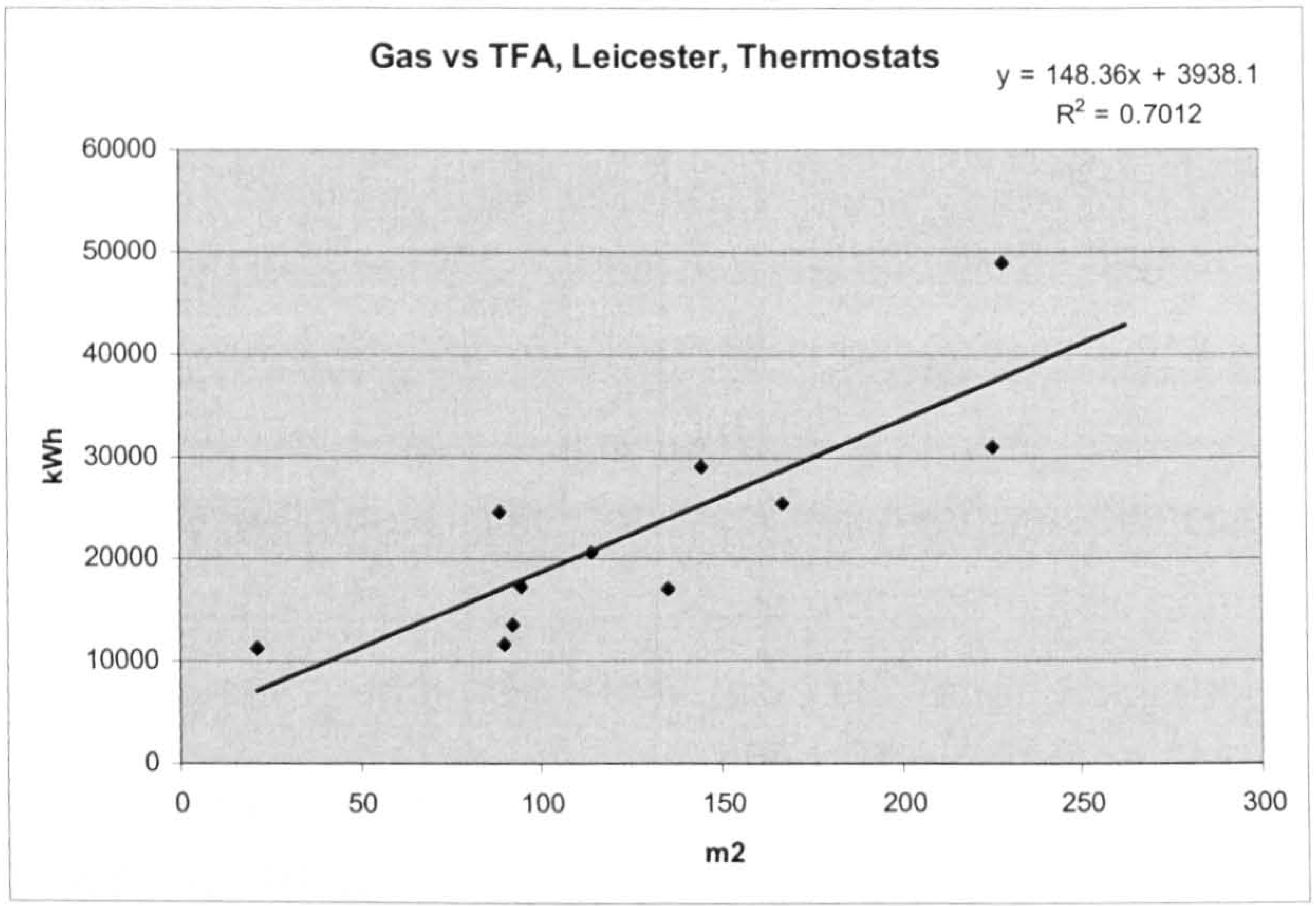


Figure 7.40. Gas consumption regressed against TFA, Leicester terraces, thermostats

For the 7 Sheffield detached dwellings without thermostats regressing both electricity and gas consumption against TFA produced high r^2 values, 0.5694 and 0.6785 (p-values 0.050 and 0.023) respectively, on visual inspection these seemed unrepresentatively high due to the degree of scatter, however they still suggested some level of correlation. For the regression of gas consumption against TFA for the detached dwellings with thermostats (35 records) an r^2 value of 0.3582 (p-value 0) was obtained, which on visual inspection seemed consistent (Figure 7.41). In the case of the Sheffield semis no significant correlations were found and the plots exhibited a high degree of scatter.

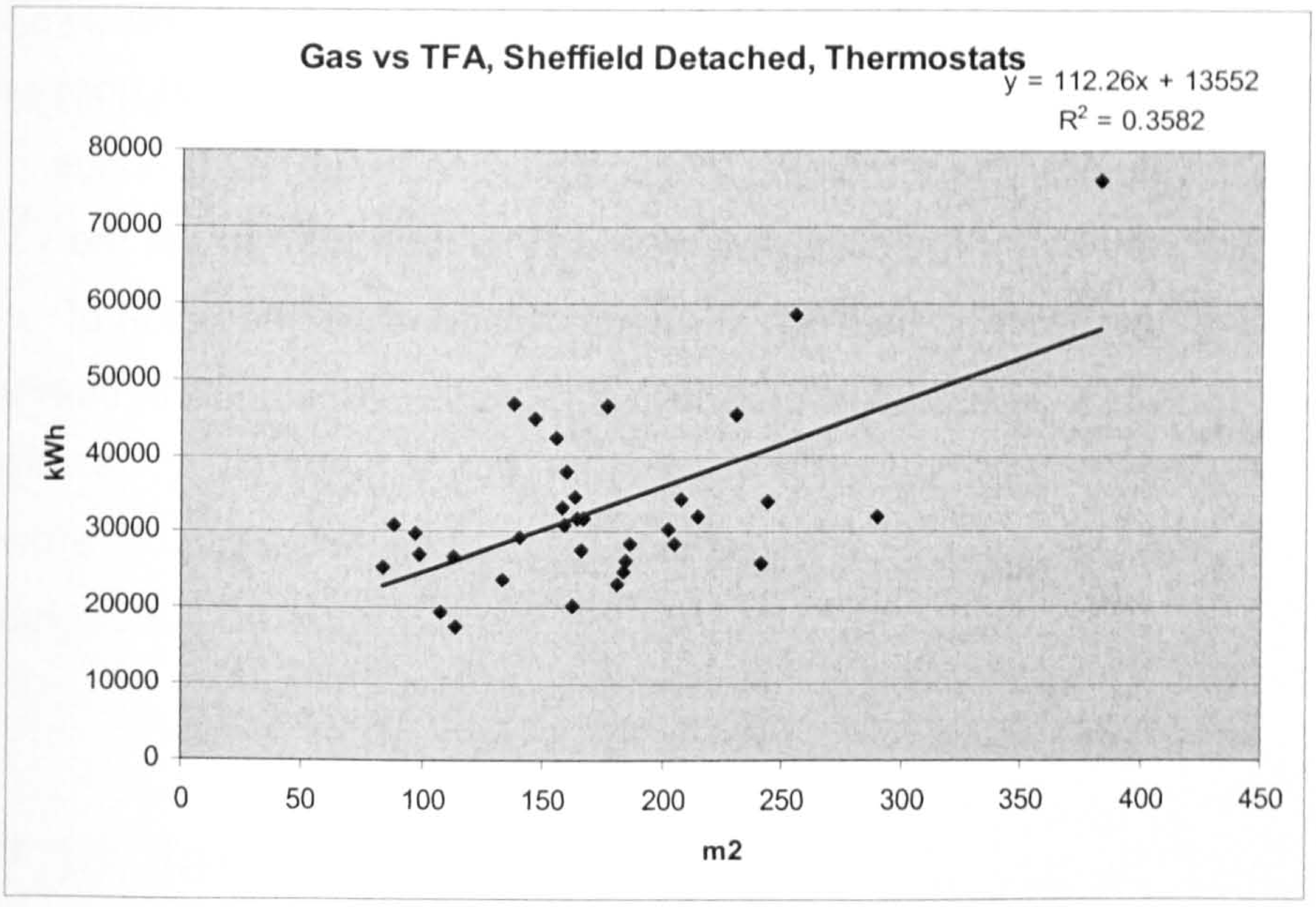


Figure 7.41. Gas consumption regressed against TFA, Sheffield detached, thermostats

As significant correlations with the presence of thermostats seemed to exist, it was decided to regress thermostat setting data (converted to °C and averaged for respondents who reported a range) against electricity and gas consumption for the combined dataset and each of the three built form groups, but this failed to produce any significant relationships. In addition, TFA was regressed against thermostat settings to determine whether there was any indication that respondents living in larger dwellings set them higher than those in smaller dwellings, as a check on the adequacy of heating systems. This also failed to yield any results worth of note.

7.13. Combinations of heating system controls

Sufficient numbers of records existed within the combined dataset to group the data by TRVs, mechanical/digital controls and thermostats, and this produced another important result. When grouped on controls and thermostats only the r^2 value for gas consumption regressed against TFA was 0.4471 (p-value 0) for dwellings with digital controls and thermostats, very close to the r^2 value of 0.4444 (p-value 0.013) for those with digital controls but without thermostats (43 and 13 records respectively). However, when the 17 dwellings reporting digital controls and thermostats but without TRVs were removed from the regression the r^2 value for the remaining 27 records rose to 0.5782 (p-value 0, Figure 7.42) which was by far the strongest relationship found for any of the categories and 0.1197 higher than the next strongest relationship (the value of 0.4471, p-value 0, found for when dwellings without TRVs were included in this group).

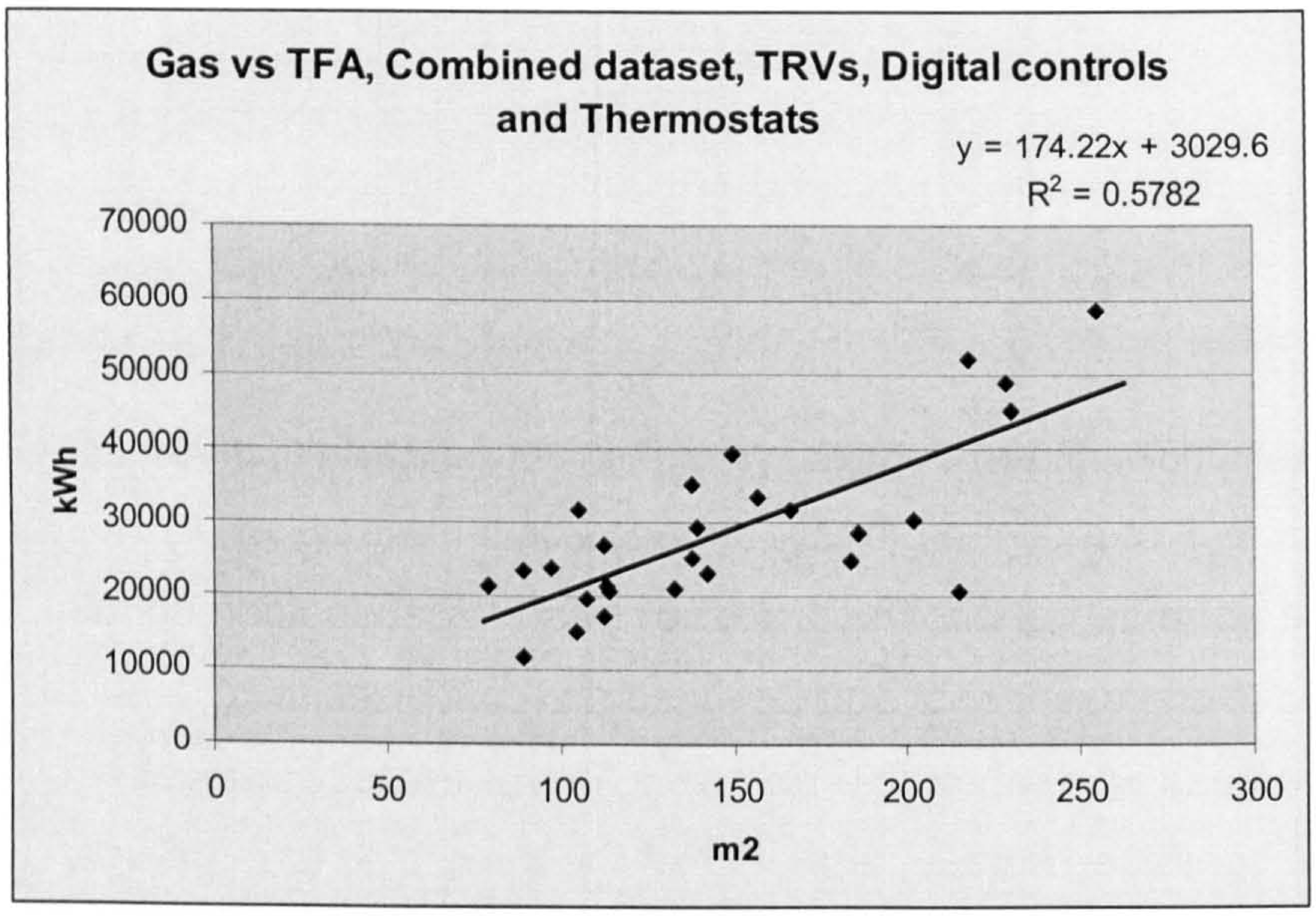


Figure 7.42. Gas consumption regressed against TFA, combined dataset, TRVs, digital controls and thermostats

The stronger relationships between gas and TFA found for the dwellings with more sophisticated heating system controls is valuable evidence that occupants are indeed using these controls to optimise their levels of thermal comfort (section 2.2.2).

Sadly the lack of conclusive evidence on which to base a system for the ranking of the different types of control and the failure to find any distinct clusters within the dataset using these variables confounded attempts to analyse these relationships further. This is most likely due to the weaker relationships and higher levels of scatter found in the regressions within the other categories, however these results do show that there is a clear potential to produce significant results from analyses of larger datasets.

7.14. Energy efficient light bulbs

As discussed in section 3.2.5 the number of energy efficient light bulbs in use in dwellings has been suggested as a useful indicator of overall energy efficiency. To test this, the numbers of bulbs that respondents reported in use were plotted against electricity consumption for the combined and individual datasets, however in this case no correlations were found.

7.15. Tenure

For the combined dataset the relationship between gas consumption and TFA was stronger for owner-occupied, owned outright dwellings (r^2 value 0.2852, p-value 0, Figure 7.43) than for owner-occupiers with mortgages (r^2 value 0.2459, p-value 0). This pattern was repeated, although the relationships were weaker, for the regression of electricity consumption against TFA (r^2 value 0.1503, p-value 0, for dwellings owned outright, but only 0.0281 (p-value 0.245) for mortgaged properties, with both plots showing high degrees of scatter).

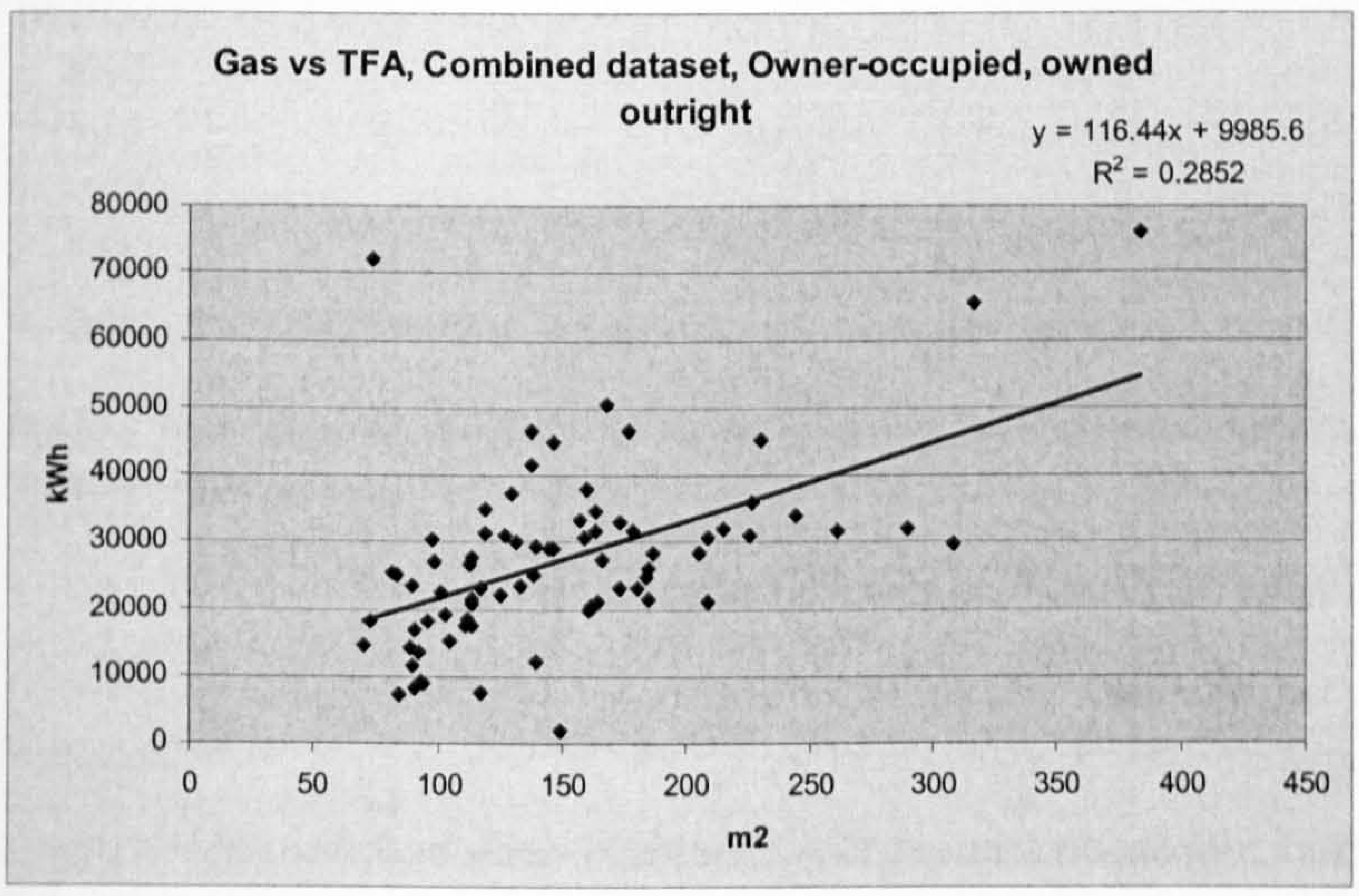


Figure 7.43. Gas consumption regressed against TFA, combined dataset, owner-occupied, owned outright

Leicester was the only study area with rented properties, and regression of TFA against tenure subsets produced some interesting results. The records were categorised into 'owner-occupied, owned outright', 'owner-occupied, with mortgage' and 'all rented'[8]. Gas consumption regressed against TFA produced correlations of 0.3789 and 0.4302 for the last two (p-value's 0.025 and 0.077) although a high degree of scatter was evident on both plots. The r^2 value for the 'owner-occupied, owned outright' dwellings was much lower (0.0961). An interesting result was that for the rented properties the regression of electricity consumption against TFA produced an r^2 value of 0.4552 (p-value 0.032) but only 10 records were available

For the Sheffield dwellings this differentiation into tenure types improved the r^2 values for gas against TFA, although the correlations remained poor for the semi-detached dwellings. Very few rented properties were found in the Sheffield study area and none of these respondents provided completed mandates. For the two categories of owner-occupancy the best r^2 was 0.4454 (p-value 0) obtained for gas consumption against TFA for owner-occupied, owned-outright detached properties (Figure 7.44).

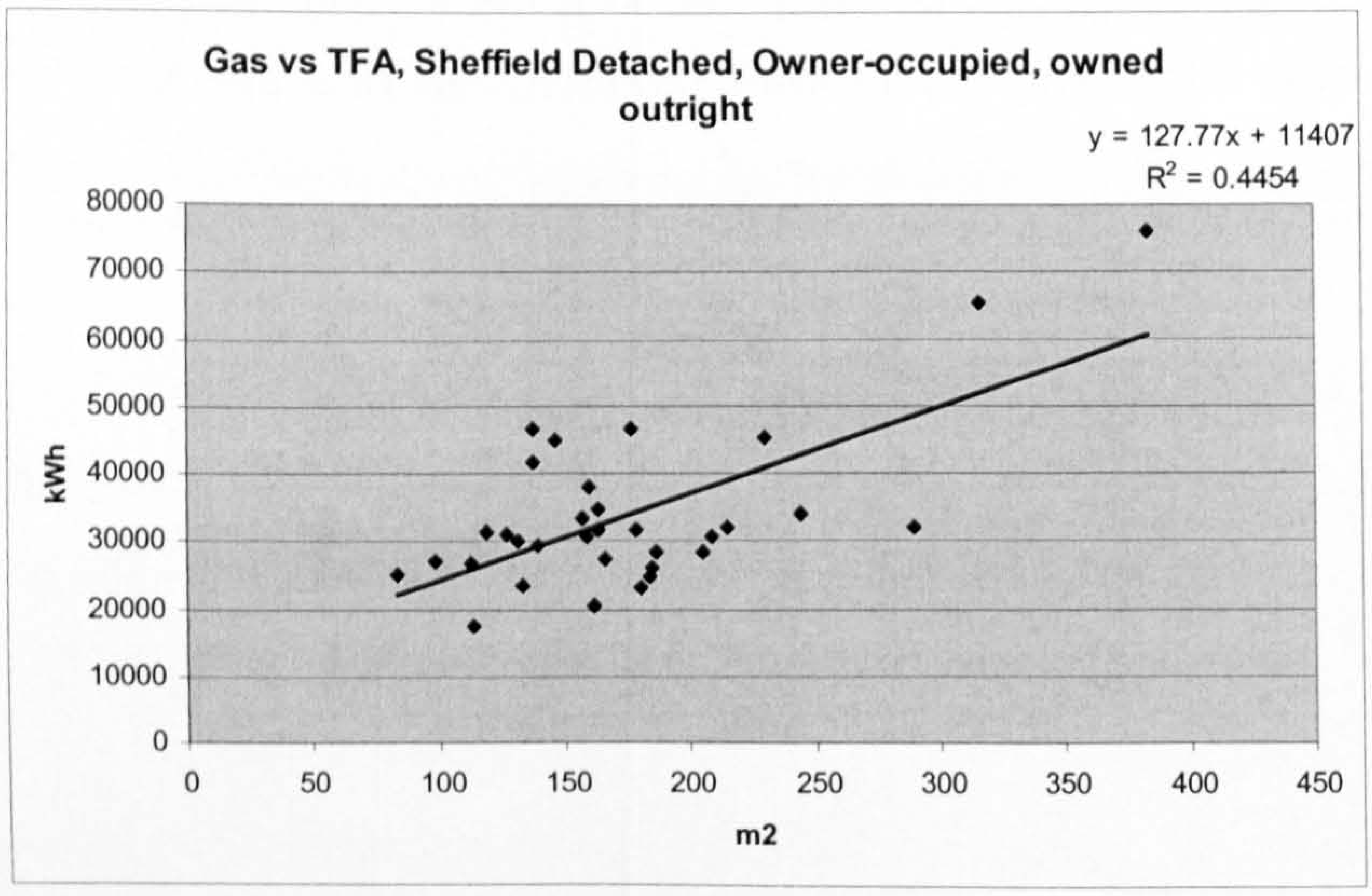


Figure 7.44. Gas consumption regressed against TFA, Sheffield detached, owner-occupied, owned outright

[8] Includes council and housing association houses as well as the two categories of privately rented dwellings.

7.16. Employment

Categorising households by employment (in terms of the number of householders in full-time or part-time employment, in full-timed education or retired) led to the greatest level of disaggregation of the data of all the analyses described here. Within the combined dataset the only relationships of note were for gas consumption regressed against TFA for households with two full-time employed occupants only and those with one retired occupant only, for which the r^2 values were 0.3063 and 0.2992 (p-values 0.011 and 0.010, Figures 7.45 and 7.46).

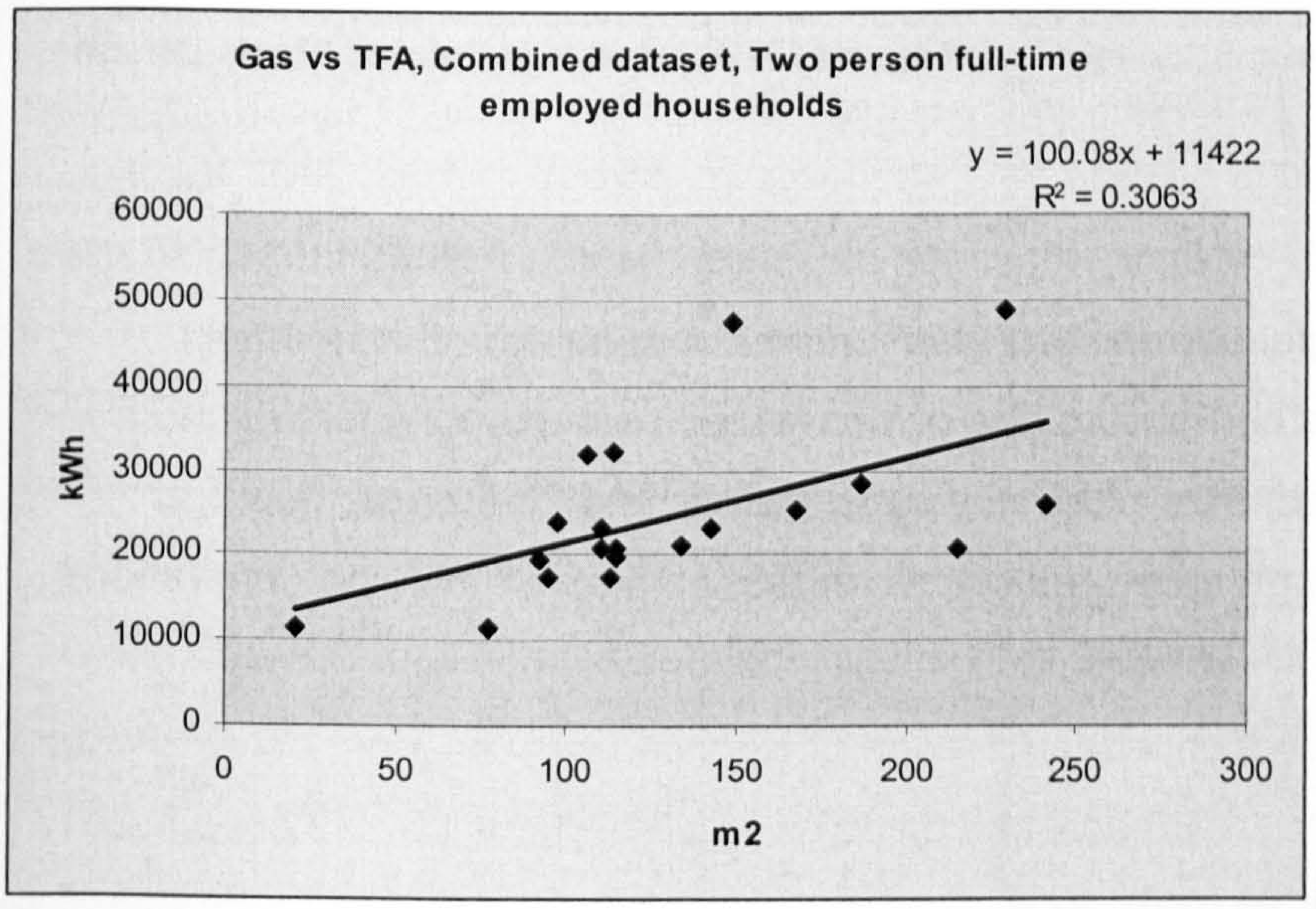


Figure 7.45. Gas consumption regressed against TFA, combined dataset, two person full-time employed households

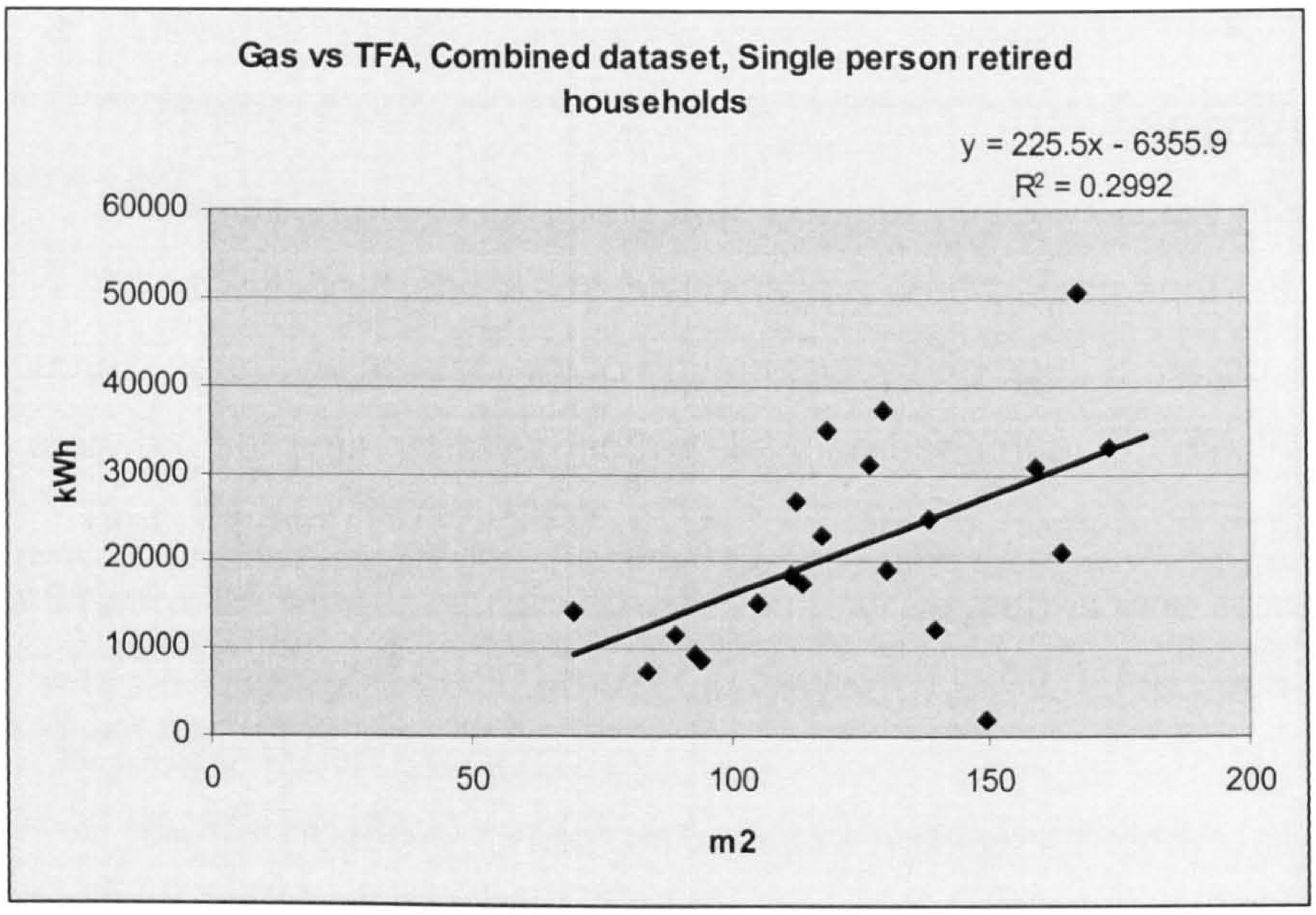


Figure 7.46. Gas consumption regressed against TFA, combined dataset, single person retired households

The only sub-category for which sufficient records existed that could have produced meaningful correlations was for the households in the Sheffield detached dwellings comprising one or two retired persons only, for which 25 records were available for electricity consumption and 20 for gas, however somewhat surprisingly when both were regressed against TFA the correlations were insignificant.

7.17. Chapter summary

The results described in this chapter highlighted many variables and potential relationships for further study. The most notable relationships between TFA and either electricity or gas consumption found for when the records in the combined dataset and the separate samples were categorised by the data collected by the questionnaire have been discussed.

Although no consistently high correlations were found within each set of categorisations these analyses were useful in informing the selection and justification of variables for the confirmatory analyses.

A notable observation from these analyses is the paucity of significant relationships between energy consumption and TFA found for the Sheffield semis, which is again evident in the next chapter.

An intriguing result was found for the combined dataset when sub-divided using the three variables for TRVs, mechanical/digital controls, and thermostats. Although attempts to further investigate the combined influence of these variables failed, these results confirm the potential for interesting results from further investigation with larger datasets.

Chapter 8. Confirmatory Analyses and Discussion of Key Findings

8.1. Introduction

This chapter describes the use of multiple regression as a confirmatory technique to further analyse the influences of those variables suggested by the exploratory analyses as being most significant in terms of determining differences in domestic energy consumption within the samples and discusses the most important results from the analyses of the matched consumption and questionnaire data from the Leicester and Sheffield study areas.

The first two sections discuss the results for the set variables identified from clustering of the data (Chapter 6) and includes the checks performed for evidence of collinearity and a full discussion of the significant results found for the number of bedrooms. Section 8.3 gives further evidence and discussion of the influence of homeworking.

The extraction of final sets of the most significant explanatory variables found for electricity and gas consumption is covered in section 8.7, and section 8.7.1 discusses the variables for which weaker correlations with energy consumption were found.

8.2. TFA, occupancy and dwelling age

The analyses reported in chapters 6 and 7 identified total floor area (TFA) and occupancy as indicators of domestic energy consumption, supporting the results of previously published studies. As is discussed in section 6.4 total occupancy (denoted TotOcc in tables) which includes children, was a better explanatory variable than the number of adults in each dwelling and therefore is used in the analyses described here. As these were the two strongest "continuous" variables identified from clustering (chapter 6) and simple regression (chapter 7), they were used as the reference point to assess the significance of the addition of other variables into multiple regression analyses.

Electricity and gas consumption were regressed against TFA and then TFA and occupancy for each of the study areas and for the combined dataset (section 7.3). The results of these regressions (Table 8.1) show how the strengths of the relationships between these variables and electricity and gas consumption varied between the samples. The significance of the F statistic change is the same as the ANOVA significance value for regressions with TFA only.

Table 8.1. Summary results for multiple regressions with TFA and occupancy

		Sig. F Change	R2	Adj R2	ANOVA Sig
Leicester Elec	TFA only		0.133	0.115	0.009
	TFA and TotOcc	0.022	0.226	0.193	0.002
Leicester Gas	TFA only		0.432	0.417	0.000
	TFA and TotOcc	0.000	0.621	0.599	0.000
Sheffield Detached Elec	TFA only		0.055	0.033	0.120
	TFA and TotOcc	0.003	0.238	0.202	0.003
Sheffield Detached Gas	TFA only		0.402	0.387	0.000
	TFA and TotOcc	0.054	0.457	0.430	0.000
Sheffield Semis Elec	TFA only		0.002	-0.018	0.737
	TFA and TotOcc	0.002	0.177	0.144	0.008
Sheffield Semis Gas	TFA only		0.079	0.058	0.056
	TFA and TotOcc	0.545	0.086	0.045	0.137
Combined dataset Elec	TFA only		0.091	0.085	0.000
	TFA and TotOcc	0.000	0.215	0.204	0.000
Combined dataset Gas	TFA only		0.361	0.356	0.000
	TFA and TotOcc	0.000	0.441	0.433	0.000

The strongest correlations between the consumption data and TFA and occupancy were found for the Leicester sample, however the adjusted r^2 value for electricity consumption in the combined dataset is the exception to this finding. The lack of a correlation with TFA only found for electricity consumption by the Sheffield semis is difficult to explain within the limits of the dataset, but this correlation becomes significant at the $p<0.05$ level with the addition of occupancy. Another weak correlation between electricity consumption and TFA was found for the Sheffield detached sample, but this also becomes significant at the $p<0.05$ level with the addition of occupancy.

The only adjusted r^2 value not improved by the addition of occupancy is for gas consumption by the Sheffield semis, which is the only correlation to produce an ANOVA significance value above 0.05 with both TFA and occupancy.

Dwelling age is another established indicator of differences in domestic energy consumption (sections 6.4 and 7.3). Table 8.2 gives the key statistics for the multiple regressions for which dwelling age was added to TFA and occupancy. As the number of records in each case is the same as for the corresponding regressions on TFA and occupancy only (Table 8.1) they are directly comparable.

Table 8.2. Summary results for dwelling age added to the multiple regressions for consumption with TFA and occupancy

		Pearson correlation	Sig. F Change	R2	Adj R2	ANOVA Sig.
Leicester	Elec	0.174	0.427	0.242	0.188	0.008
	Gas	0.054	0.295	0.579	0.540	0.000
Sheffield detached	Elec	-0.247	0.480	0.248	0.193	0.008
	Gas	-0.366	0.369	0.469	0.247	0.000
Sheffield semis	Elec	-0.142	0.737	0.179	0.128	0.023
	Gas	-0.274	0.263	0.113	0.051	0.157
Combined dataset	Elec	0.100	0.227	0.237	0.221	0.000
	Gas	0.139	0.241	0.429	0.415	0.000

The positive correlations with age for the Leicester sample are difficult to explain but may be due to respondent error in reporting pre and post 1900 dwellings (the only age brackets in this sample, see section 4.3) and are likely to have introduced an element of error into the results for the combined dataset.

However, three strong correlations between gas consumption and TFA were found within dwelling age brackets (section 7.3) and the significance of dwelling age as a determining variable for the energy consumption clusters discovered in the data (chapter 6) made it difficult to dismiss dwelling age as an explanatory variable for energy consumption.

8.3. Numbers of rooms and bedrooms

Crosstabulation with the clusters found for energy consumption within both the individual and combined datasets showed that the number of bedrooms was consistently a stronger explanatory variable than the number of rooms (sections 6.4 and 6.7) however simple linear regression produced some results for which the influence of the number of rooms was stronger (section 7.4). To confirm the relative significances of these variables both were added to the multiple regressions of electricity and gas consumption with TFA and occupancy.

The Pearson correlations and the ANOVA significance values for these regressions are given in Table 8.3 which shows that in only one case (gas consumption by the Sheffield detached sample) was a higher Pearson correlation found with the number of rooms. With the exception of gas consumption by the Sheffield semis all these regressions produced correlations that were significant at the $p<0.05$ level, however this is unsurprising given the results for the regressions using only TFA and occupancy. As the ANOVA significance values show, the addition of either variable improved the correlations to the point that they only marginally failed this test.

Table 8.3. Comparison of Pearson correlations for the numbers of rooms and bedrooms when added to multiple regressions of electricity and gas consumption against TFA and occupancy

	Leicester terraces		Sheffield Detached		Sheffield Semis		Combined datasets	
	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas
Number of rooms								
Pearson correlation for multiple regressions with TFA and TotOcc	0.332	0.562	0.276	0.500	0.282	0.381	0.339	0.510
ANOVA significance of multiple regressions with TFA and TotOcc	0.007	0.000	0.019	0.000	0.009	0.053	0.000	0.000
Number of bedrooms								
Pearson correlation for multiple regressions with TFA and TotOcc	0.368	0.651	0.398	0.434	0.583	0.389	0.466	0.562
ANOVA significance of multiple regressions with TFA and TotOcc	0.008	0.000	0.005	0.000	0.000	0.052	0.000	0.000

A final assessment of the significance of the number of bedrooms as an explanatory variable for energy consumption is shown by Table 8.4. This gives the correlations for the number of bedrooms only with electricity and gas consumption, the F statistic changes for the addition of this variable to multiple regressions with TFA and occupancy and with TFA and occupancy plus dwelling age and the number of rooms, and also the r^2, adjusted r^2 and ANOVA significance values for each regression.

As evidenced by the changes in the F statistic the addition of the number of bedrooms improves the correlations with electricity consumption more than the correlations with gas consumption, with the exception of the Leicester terraces. In some cases, particularly for the Leicester terraces and gas consumption by the Sheffield detached sample, this statistic is notably high and serves to reduce the adjusted r^2 values. The most plausible explanation for this is that these were the three cases for which surprisingly strong correlations with TFA and occupancy only were found, and therefore it should be expected that the further addition of further variables would have a more limited impact on these correlations.

Where the r^2 values are shown to fall this statistical impossibility is explained by the addition of this variable leading to a reduction in the number of records being analysed.

Table 8.4. Statistics for the number of bedrooms when regressed against energy consumption and when added to multiple regressions with TFA, occupancy, dwelling age and number of rooms

		Sig. F Change	R2	Adj R2	ANOVA Sig
Leicester Elec	No Bedrooms only		0.150	0.005	0.005
	TFA and TotOcc	0.899	0.227	0.008	0.008
	TFA, TotOcc, Age and No Rooms	0.872	0.244	0.041	0.041
Leicester Gas	No Bedrooms only		0.424	0.000	0.000
	TFA and TotOcc	0.948	0.621	0.000	0.000
	TFA, TotOcc, Age and No Rooms	0.707	0.604	0.000	0.000
Sheffield Detached Elec	No Bedrooms only		0.157	0.007	0.007
	TFA and TotOcc	0.061	0.273	0.005	0.005
	TFA, TotOcc, Age and No Rooms	0.098	0.277	0.025	0.025
Sheffield Detached Gas	No Bedrooms only		0.188	0.005	0.005
	TFA and TotOcc	0.943	0.485	0.000	0.000
	TFA, TotOcc, Age and No Rooms	0.891	0.510	0.000	0.000
Sheffield Semis Elec	No Bedrooms only		0.340	0.000	0.000
	TFA and TotOcc	0.000	0.400	0.000	0.000
	TFA, TotOcc, Age and No Rooms	0.000	0.407	0.000	0.000
Sheffield Semis Gas	No Bedrooms only		0.151	0.007	0.007
	TFA and TotOcc	0.054	0.163	0.052	0.052
	TFA, TotOcc, Age and No Rooms	0.139	0.222	0.058	0.058
Combined dataset Elec	No Bedrooms only		0.227	0.000	0.000
	TFA and TotOcc	0.000	0.274	0.000	0.000
	TFA, TotOcc, Age and No Rooms	0.001	0.298	0.000	0.000
Combined dataset Gas	No Bedrooms only		0.316	0.000	0.000
	TFA and TotOcc	0.077	0.459	0.000	0.000
	TFA, TotOcc, Age and No Rooms	0.491	0.447	0.000	0.000

8.4. Collinearity diagnostics for TFA, occupancy, dwelling age and numbers of rooms and bedrooms

Evidence for collinearity was a concern when interpreting the results of these multiple regressions, especially as it is reasonable to expect that the number of bedrooms may be closely related to TFA, occupancy and the number of rooms. Furthermore, the limited number of records analysed meant that collinearity was expected to become apparent for regressions with relatively small numbers of variables.

Figure 8.1 shows that there is indeed a correlation between the numbers of rooms and bedrooms in the dwellings in the combined dataset, however this alone is not sufficient evidence for collinearity.

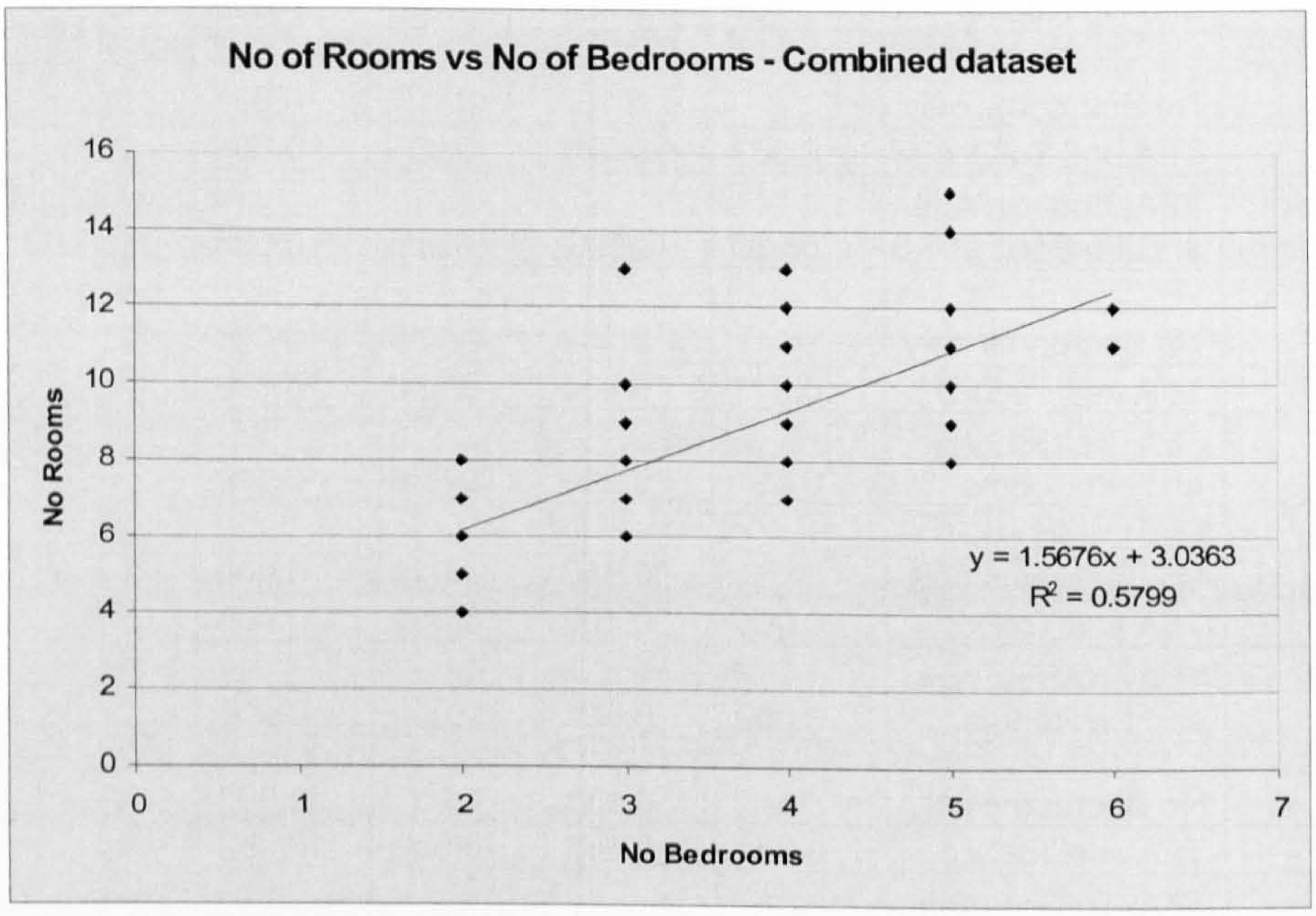


Figure 8.1. Plot of the number of rooms against the number of bedrooms for the combined dataset

As discussed in section 5.6 the small number of records and large number of variables dictated that the measure of collinearity for these analyses was the condition index (from the collinearity diagnostics output). Collinearity is a concern where this is above 15, and a value above 30 denotes a serious problem with collinearity.

Consistent evidence of a notable increase in the condition index would have been sufficient to reject the use of the number of rooms and the number of bedrooms in the same multiple regression analyses, however as shown in Table 8.5 this was not found. The table gives the condition indicies for the multiple regressions of consumption against the five variables for TFA, occupancy and dwelling age, and once the impacts of the number of rooms and then the number of bedrooms have been accounted for. These are taken from the same multiple regressions, rather than comparing that statistics for separate regressions with the additional variables added in stages, in order that the results in each column apply to the same number of records.

Table 8.5. Collinearity statistics for multiple regressions with TFA, occupancy, dwelling age, number of rooms and number of bedrooms

	Leicester terraces		Sheffield Detached		Sheffield Semis		Combined datasets	
	Elec	Gas	Elec	Gas	Elec	Gas	Elec	Gas
Condition index for TFA, TotOcc, and Age	9.749	10.026	13.775	13.589	12.937	13.178	9.724	9.648
Condition index for TFA, TotOcc, Age and No Rooms	18.431	21.126	21.341	21.292	16.899	18.481	14.018	14.309
Condition Index with No Bedrooms	26.438	24.738	21.754	21.679	23.426	23.456	19.729	20.056
Change in Condition Index after addition of No Rooms	8.682	11.100	7.566	7.703	3.962	5.303	4.294	4.661
Change in Condition Index after addition of No Bedrooms	8.007	3.612	0.413	0.387	6.527	4.975	5.711	5.747

The table shows that with the exception of the combined dataset the condition indicies for TFA, occupancy and dwelling age are already approaching 15 and the relative subsequent rises in this value should be interpreted with this in mind.

The last two rows show the changes in the condition indices attributable to the number of rooms and the number of bedrooms. For the Sheffield detached sample there is little change in the condition index after the number of bedrooms has been accounted for. For electricity and gas consumption by the Leicester terraces and gas consumption by the Sheffield semis the change in the condition index accounted for by the number of bedrooms is less than the change accounted for by the addition of the number of rooms to the other three variables. The highest rise accounted for by the number of bedrooms is for electricity consumption by the Leicester terraces.

In light of the limitations of the dataset the lack of consistency in these changes was sufficient evidence not to exclude any of the variables from being analysed simultaneously in further multiple regressions.

Other than TFA and occupancy the number of bedrooms was the most statistically significant explanatory variable for energy consumption found by the study. As this variable has to date received little attention in previously published studies and is not commonly used in existing energy models these results merit more detailed discussion

8.5. Discussion of the significance of the number of bedrooms as an explanatory variable for energy consumption

An important antecedent to this thesis is the Australian study conducted by Perkins (2002) but this could not investigate any relationships between the numbers of bedrooms with energy consumption as it was based on a survey of dwellings built to the same standardized plans. However, in the UK this data is being collected as part of the Homes Energy Efficiency Database (HEED) being developed by the Energy Savings Trust (Amato and Owen, 2006) - but this was still in the early stages of development at the time this study was completed. The only publication mentioning the use of this variable in relation to the assessment of dwelling energy consumption was in a study conducted by a private firm in Washington State in 1998. This is provides useful supporting evidence as, like this study, it utilised annual billing data for the year prior to the study being conducted. The study assess the value of using the number of bedrooms to control for the likely change in occupancy levels if a household had moved out of a dwelling after the consumption data had been collected but before the dwelling was surveyed. The conclusion was that knowing the number of bedrooms was indeed a useful control over the impact of recent movers on dwelling energy consumption (Colton, 1998). However, these results show it may be of greater value than a simple control variable. So why might this be so?

In the absence of published evidence for comparison it is only possible to speculate on this relationship and recommend that it is the subject of close attention in future domestic energy studies. The simplest assertion is that it acts as a proxy for TFA, and indeed there are clear correlations between the two even if there is no statistically significant level of collinearity, and similarly for the number of rooms. Even though the definition of a room was given in the guidance notes accompanying the questionnaire it is still more open to interpretation by non-professionals and is defined differently by different surveys.

These two explanations probably account for much of the relationships, however the changing composition of UK households (section 3.9) may be another factor. In smaller households occupants are more likely to divide their time spent in each room more discretely than in family households, where more rooms can be expected to be in use at any one time. Some additional evidence to support this comes from the use of portable electric heaters, for which weak correlations were found with the number of bedrooms for the Sheffield semis (Spearman correlation 0.332, approximated significance value 0.016) and for the combined dataset (Spearman correlation 0.163, approximated significance value 0.044). As the questionnaire did not ask respondents to specify where each type of secondary heating was in use it was not possible to state conclusively that these results were indicative of occupants using these appliances specifically heat their bedrooms the high significance of bedrooms as an explanatory variable means that investigating this factor could yield useful results in future studies.

Furthermore, the increased uptake of brown goods by consumers may be indicative of more technology making its way into bedrooms (TVs, PCs, hi-fi systems, etc) – the attraction of the comfort of being able to watch TV, listen to music and even play video games and access the internet whilst lying in bed is obvious. Another possible explanation is the use of bedrooms as home offices, whether or not the room is also in regular use as a bedroom (the definition of 'bedroom' used for the questionnaire being only 'any room in which a bed is permanently set up'). This is particularly relevant to the conclusions from this study as the data on whether or not respondents reported regularly working from home also emerged as a significant explanatory variable and is discussed in more detail later in the next section. If the importance of the number of bedrooms as an explanatory variable for domestic energy consumption really is more significant now than in the past this would be convincing evidence on which to base more focused studies, for example monitoring the proportions of time occupants spend in each room of their dwelling. The lack of previous studies using this variable means its impact and any changes in its influence are still not adequately quantified but the evidence from this study suggests doing so would provide fertile ground for further research.

8.6. Homeworking

The study found strong evidence for homeworking as a determinant of differences in domestic energy consumption. The number of homeworkers in the UK rose by 65% from 1997 to 2001, accounting for 2.2 million workers or 74% of the employed population (Cyber Buisness Centre, 2002). However, the impact of householders regularly working from home is a variable that has received scant attention in studies of domestic energy consumption. This is unsurprising given that the option to work from home (also termed teleworking) is relatively new for many employees. The proportions of homeworkers in the three study areas were actually much lower. For those respondents reporting at least one member of the household in full time employment 50% of those from the Leicester terraces and 53% of those from the detached Sheffield dwellings reported regularly working from home, but this was reported for only 22% of those from the Sheffield semis. A possible explanation for this difference may be the qualification of 'regularly' used in the questionnaire.

The evidence from the clustering and simple linear regressions suggested homeworking was a potentially significant variable (sections 6.6 and 7.15). To further assess the strength of homeworking as an explanatory variable it was added to the multiple regressions with TFA, occupancy, dwelling age and the numbers of rooms and bedrooms.

As is shown in Table 8.6 the change in the F statistic was significant at the $p<0.05$ level when added to the multiple regressions for the combined dataset and for electricity consumption by the Sheffield semis, with some evidence for significance for gas consumption by the Leicester terraces. In no case were the results invalidated by a condition index above 30, although the indicies were close to 30 for both the Leicester results.

Table 8.6. Statistics for homeworking when added to multiple regressions with TFA, occupancy, dwelling age, number of rooms and number of bedrooms

		Sig. F Change	R2	Adj R2	ANOVA Sig
Leicester Elec	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.244	0.149	0.041
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.337	0.261	0.148	0.054
Leicester Gas	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.604	0.538	0.000
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.074	0.646	0.573	0.000
Sheffield Detached Elec	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.277	0.182	0.025
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.906	0.278	0.160	0.049
Sheffield Detached Gas	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.510	0.440	0.000
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.600	0.514	0.438	0.000
Sheffield Semis Elec	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.407	0.341	0.000
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.008	0.495	0.426	0.000
Sheffield Semis Gas	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.222	0.127	0.058
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.705	0.225	0.109	0.098
Combined dataset Elec	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.298	0.272	0.000
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.034	0.321	0.291	0.000
Combined dataset Gas	TFA, TotOcc, Age, No Rooms and No Bedrooms		0.447	0.424	0.000
	Homeworking plus TFA, TotOcc, Age, No Rooms and No Bedrooms	0.032	0.468	0.441	0.000

These results are unsurprising given that homeworkers can be expected to have different energy regimes – heating their homes for longer periods and using appliances during the day. Unfortunately the additional questions asking what appliances were in use by homeworkers were left unanswered by most respondents, therefore it was not possible to add to this conclusion using these variables. However, the trend towards homeworking is increasing and therefore this is strong evidence for this variable to be included in future energy studies where it is not possible or desirable to monitor subject behaviour directly.

8.7. Establishment of final sets of explanatory variables

To conclude the confirmatory stage of the analysis all the variables collected from the questionnaire that were identified as having weaker relationships with gas or electricity consumption were entered into multiple regressions with TFA, occupancy, dwelling age and the numbers of rooms and bedrooms.

Beyond the first five variables it was impossible to produce a definitive set of explanatory variables that were applicable to either electricity or gas consumption across the three study areas and for the combined dataset. However, some variables did produce notable, if inconsistent, correlations, and where these were found it was possible to use multiple regression to establish the best sets of explanatory variables for electricity and gas consumption within the study areas and for the combined dataset.

This section presents the summary tables for the best sets of explanatory variables for each sample (Tables 8.7-8.15) and gives the justifications for the inclusion of each.

The order in which the variables appear in these tables is the order in which they had to be entered to produce the associated statistics. This is important to note as introducing new variables tended to reduce the number of records being analysed and change the statistics associated with variables already accounted for. In most cases these changes were minor, but an exception is noted in Table 8.12 for gas consumption by the Sheffield semis.

These changes were caused by a reduction in the number of records and this is reported in the summary tables. Although it was impossible to avoid some reduction in the number of records being analysed as more variables were introduced every effort was made to limit this. Where correlations were found with variables that led to notable reductions in the number of records being analysed the results were compared to those for the addition of other variables before finalising the groups and orders given in the tables.

An additional problem was collinearity, which led to condition indicies approaching or exceeding 30 after only a small number of variables had been added. The best example of this is table 8.8 for electricity consumption by the Leicester terraces, for which it was only possible to include 7 explanatory variables before the evidence for collinearity meant it was meaningless to proceed further. The notes at the end of each table give whether the final condition index exceeded 30 or was so close to this as to make further additions meaningless.

The tables are discussed with reference to the relative strengths of the correlations found in each. Discussion of the evidence for each of the variables included in these tables is in section 8.8.

Table 8.7. Summary statistics for the best explanatory variables for electricity consumption by the Leicester terraces

Leicester - Elec	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	46	0.244	0.149	0.041	0.041
Main heating - Storage heaters	46	0.413	0.323	0.002	0.001
Homeworking	46	0.428	0.322	0.337	0.002
At this point Condition Index close to 30					

Here the set of explanatory variables is limited to the first five variables and homeworking, plus the use of storage heaters. Storage heaters were reported for only 3 of these records (which were also the only three records for which their use was reported in the entire matched dataset). However, the significance of the change in the F statistic suggests that their use was having a sufficient impact on electricity consumption to be picked up even within the limits of these analyses. The lack of a reduction in the number of records due to the addition of these two variables useful as it means the increase in r^2 and adjusted r^2 values is an accurate measure of the strength of this variable within the dataset. The influence of homeworking is minor but does make some improvement to the r^2 value at the cost of a reduction of only 0.001 to the adjusted r^2 value. The cumulative ANOVA significance is evidence that the differences in these variables accurately reflect the level of variance attributable to them.

Table 8.8. Summary statistics for the best explanatory variables for gas consumption by the Leicester terraces

Leicester - Gas	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	36	0.604	0.538	0.000	0.000
Secondary heating - Gas fires	36	0.655	0.583	0.048	0.000
Glazing	36	0.690	0.612	0.086	0.000
Homeworking	36	0.719	0.636	0.107	0.000
At this point Condition Index >30					

The variable for gas fires as secondary heating appears here as the most significant explanatory variable after the influence of the five cardinal variables has been accounted for, and this is not the result of it reducing the number of records. Although the use of gas fires was not limited to the Leicester sample it was not found have such an influence in either of the Sheffield samples, or have a sufficient impact at this level of analysis to be apparent in the combined dataset.

Another variable that appears in this table but also appears as an explanatory variable for gas consumption in the combined dataset (Table 8.14) is glazing, despite the fact that single glazing was reported for only 2 dwellings in each of the Sheffield samples. This may be indicative of the presence of a small number of poorly insulated, high gas consuming dwellings within the data.

As for electricity consumption within this sample homeworking was the last variable that could be added, in this case leading to a condition index exceeding 30 despite clear improvements in the r^2 and adjusted r^2 values. As discussed in sections 6.7 and 7.6, this variable was a consistently strong explanatory variable for energy consumption across the three study areas, however it is clear that for the Leicester terraces its impact was more apparent after the inclusion of the other variables.

Again the number of records is not reduced by the additional variables and the final ANOVA significance value is significant at the p<0.05 level.

Table 8.9. Summary statistics for the best explanatory variables for electricity consumption by the detached Sheffield dwellings

Sheffield Detached - Elec	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	44	0.277	0.182	0.025	0.025
No Portable Elec Heaters	44	0.337	0.229	0.077	0.014
No PCs in use	44	0.387	0.268	0.093	0.009
Dishwasher owned	44	0.407	0.271	0.296	0.011
Homeworking	44	0.408	0.251	0.773*	0.021
*This value is exceptionally high, inclusion as the final variable here was justified on the comparatively high Pearson correlation of 0.262 with elec consumption					
At this point Condition Index close to 30					

The final correlations produced from the multiple regressions conducted on electricity consumption by this sample were the lowest found in these analyses and it is notable that the r^2 value shows relatively little improvement down the table and the adjusted r^2 value decreases after the addition of homeworking. Furthermore, the ANOVA significance value falls after the addition of portable electric heaters and PCs but increases again afterwards. Some increase in this value within the p<0.05 limit is acceptable, however the associated statistics cast doubt on the value of the last two variables. This suggests the factors influencing electricity consumption in this sample were more complex than for the terraces or semis, and the results are disappointing compared to the stronger cumulative correlations found with electricity consumption for these samples.

Table 8.10. Summary statistics for the best explanatory variables for gas consumption by the detached Sheffield dwellings

Sheffield Detached - Gas	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	41	0.510	0.440	0.000	0.000
Heating system controls	41	0.565	0.489	0.000	0.000
Thermostat	41	0.581	0.492	0.278	0.000
Homeworking	41	0.595	0.494	0.298	0.000
Boiler type*	36	0.626	0.492	0.384	0.001
*Note: Addition of this variable reduces the number of records and changes other values - Sig F Change for homeworking becomes 0.198, and for thermostats becomes 0.363					
At this point Condition Index >30					

In contrast to the results for the multiple regressions on electricity consumption for this sample the final correlations found for gas consumption are surprisingly high. However, the improvements in the r^2 and adjusted r^2 values are minimal after the addition of the variable for heating system controls.

As stated in the table the addition of the variable for boiler type had a notable impact on the F statistic change for homeworking and thermostats, decreasing the former but increasing the latter. This change, caused by the reduction in the number of records, demonstrates the limitations of the size and completeness of the dataset. However, the consistency in the ANOVA significance values up to and including the addition of homeworking is evidence that the differences in these variables accurately reflect the level of variance attributable to them.

Table 8.11. Summary statistics for the best explanatory variables for electricity consumption by the Sheffield semis

Sheffield Semis - Elec	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	51	0.407	0.341	0.000	0.000
Homeworking	51	0.495	0.426	0.008	0.000
No Portable Elec Heaters	51	0.524	0.446	0.110	0.000
No TVs in use	50	0.578	0.495	0.060	0.000
Washing machine use	36	0.646	0.532	0.122	0.000
At this point Condition Index >30					
Alternative final result					
No digiboxes in use	45	0.598	0.495	0.251	0.000
At this point Condition Index close to 30					

This table is another example of the complexities of trying to establish the most powerful set of explanatory variables for each dataset. In this case the addition of homeworking is clearly justifiable, as is the number of TVs despite the loss of 1 record. Up to this point the r^2 and adjusted r^2 values show notable improvements at each stage and the ANOVA significance value remains at 0.

After this two possible variables presented themselves as final additions but these had differing effects. Adding washing machine use produced the highest cumulative correlations and (within the limitations of the dataset) an acceptable F statistic change, but resulted in a significant reduction in the number of records and a condition index exceeding 30. The alternative final variable was the number of digiboxes in use, which produced a smaller reduction in the number of records but had the opposite impact to washing machine use on the other statistics. Neither variable was preferable based on the ANOVA significance value as neither affected this statistic.

Table 8.12. Summary statistics for the best explanatory variables for gas consumption by the Sheffield semis

Sheffield Semis - Gas	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	47	0.222	0.127	0.058	0.058
Thermostat	47	0.252	0.139	0.217	0.059
Heating system controls*	47	0.301	0.175	0.106	0.039
Wall insulation	45	0.391	0.256	0.038	0.013
Boiler type	43	0.413	0.253	0.360	0.023
*Variable only becomes significant after the addition of the previous variable					
At this point Condition Index >30					

The correlations in this table are relatively weak and the ANOVA significance values show that it was difficult to explain the variation in gas consumption for this sample using the variables in the dataset.

It also contains two confusing results. The relative strength of the variable for heating system controls (measured by the change in the F statistic) was only apparent after the addition of the variable for thermostats despite neither reducing the number of records being analysed. In this case it would be expected that the adjusted r^2 value would decrease or increase only marginally and that the ANOVA significance value would increase, but this is not the case. Furthermore, the reduction in the number of records associated with the addition of wall insulation might be expected to produce some improvement in the correlations, but the level of this improvement is surprising given that only 2 records are excluded and therefore the results are far from conclusive.

Table 8.13. Summary statistics for the best explanatory variables for electricity consumption for the combined dataset

Leicester and Sheffield combined - Elec	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	142	0.298	0.272	0.000	0.000
Homeworking	142	0.321	0.291	0.032	0.000
Main heating - Storage heaters	142	0.377	0.345	0.001	0.000
No TVs in use	139	0.397	0.360	0.100	0.000
Showers per week	122	0.436	0.391	0.045	0.000
No digiboxes in use	106	0.451	0.393	0.362	0.000
No PCs in use	101	0.465	0.398	0.367	0.000
No Portable Elec Heaters	101	0.468	0.395	0.473	0.000
At this point Condition Index close to 30					

This table shows that despite the inconsistencies in the results for the individual study areas to some extent it was possible to produce a set of explanatory variables for electricity consumption for the larger combined dataset. The emergence and relative significance of homeworking as the strongest explanatory variable after the cardinal five (as is also true for the results for gas consumption that follow) supports the results of the exploratory analyses (chapters 6 and 7).

The presence of storage heaters in the third row shows that despite the small number of dwellings for which they were reported their influence on electricity consumption was significant within the limitations of the dataset.

With the exceptions of dishwasher ownership and washing machine use all the variables identified as having a statistically significant influence on electricity consumption for the individual samples appear in this final set. Only one (showers per week) appears here for the first time, a surprising result given the value for the change in the F statistic.

Due to the problem of having to account for the reducing number of records it is not possible to conclude that the exact order in which the variables are given is a definitive ranking of their relative influences on domestic electricity consumption. However, this table does contain the best and most justifiable set of explanatory variables found for electricity consumption by the dwellings in the combined dataset.

Table 8.14. Summary statistics for the best explanatory variables for electricity consumption for the combined dataset

Leicester and Sheffield combined - Gas	No. Records	R2	Adjusted R2	Sig. F Change	ANOVA Sig
TFA, TotOcc, Age, No. Rooms, No Bedrooms	125	0.447	0.424	0.000	0.000
Homeworking	125	0.468	0.441	0.032	0.000
Glazing	125	0.485	0.455	0.051	0.000
Boiler type	113	0.495	0.456	0.168	0.000
Wall insulation	105	0.517	0.471	0.382	0.000
Thermostat	105	0.520	0.469	0.463	0.000
At this point Condition Index close to 30					

The results for the use of multiple regression to attempt to establish the best set of explanatory variables for gas consumption for the combined dataset show that, as for electricity consumption, the statistics become less conclusive after the addition of homeworking.

In this case all the variables that appear in this table were found to have some degree of influence on gas consumption in one or more of the individual study areas, but again not all appear in this final table.

As discussed with reference to gas consumption by the Leicester terraces, the presence of glazing may be indicative of a small number of poorly insulated and high gas consuming dwellings within the samples.

The significance and ordering of the last three variables needs to be interpreted with reference to the reductions in the number of records, however the number of records excluded from top to bottom is half that for the table of multiple regressions on electricity consumption for this dataset.

As for electricity consumption this table cannot be justified as a definitive ranking of the variables or a precise measure of their levels of influence, however it does represent the best and most justifiable set of results for explaining the differences in gas consumption between the dwellings in the combined dataset.

8.7.1. Discussion of other variables for which some correlations with energy consumption were found

The multiple regression analyses which resulted in the production of the summary tables discussed in section 8.7 identified a selection of variables for which there was some evidence of influences on energy consumption. As the correlations varied to some extent in strength and significance depending on the permutations and combinations used in each analysis it is infeasible to include a complete coverage of this phase of the data analysis here. Therefore this section provides a summary of those variables for which some degree of correlation was found with gas or electricity and discusses the relevance of these results in relation to the composition of the datasets.

Wall insulation

There was some limited evidence of a relationship between gas consumption and wall insulation for the Sheffield semis. This only became evident as part of the final multiple regressions on this sample but it also emerged for the final multiple regressions on the combined dataset. It is notable that the final correlations found for gas consumption by the semis were the least satisfactory of the three samples. The appearance of this variable in the table of regressions on gas consumption for the combined dataset suggests the influence of wall insulation on gas consumption may become more apparent in larger datasets, and therefore cannot be dismissed as a chance feature of the data, it is impossible to state this conclusively based only on these results.

Glazing

Some correlation with gas consumption was found for the Leicester terraces and the influence of the distinction between dwellings reported as having predominantly single or double glazed windows was evident as an influence on gas consumption for the combined dataset. This suggests that it may be acting as an indicator of a small number of poorly insulated dwellings within the samples.

Conservatories

The evidence for the impact of conservatories from the matched data was inconclusive. Only two conservatories were reported for the Leicester terraces, along with just under one quarter of each of the two Sheffield groups. The best evidence in terms of significance came from multiple regression of conservatories with the five established variables against gas consumption for the Sheffield semis, where there was a notable positive correlation. When regressed with electricity consumption for both the Sheffield samples the correlations were much weaker and less statistically significant. However, the result that led to the ruling out of this variable for further investigation was the negative correlation found with gas consumption for the detached Sheffield dwellings, for which the Pearson correlation was over half the negative correlation found for the semis, although not as statistically significant.

Main heating system and controls

The vast majority of the dwellings were reported as having gas fuelled radiator systems as their main form of space heating. Of the Leicester terraces 3 were reported as having storage heaters as their main form of heating and there was statistically significant evidence of these dwellings being higher electricity consumers both within the Leicester sample and within the combined dataset.

The variables for heating system controls and the presence of thermostats produced some confusing results when used in the multiple regression analyses of gas consumption. Both were found to have some degree of correlation with gas consumption for both the Sheffield samples, although neither was found to have a statistically significant correlation with gas consumption for the Leicester terraces despite the fact that various combinations of controls and thermostats were reported for these dwellings. For the combined dataset only the presence of thermostats was found to have a significant enough correlation to be included in the summary table of explanatory variables for gas consumption but this was weaker than for either of the individual samples.

Secondary heating

Gas fires were the most common form of secondary heating reported for the dwellings in the three study areas (51% of the combined dataset). Despite the correlation found with gas consumption by the Leicester terraces their influence on gas consumption was not found to be statistically significant for the combined dataset.

The second most common form of secondary heating was portable electric heaters (30% of the combined dataset). This variable appears in the final multiple regression tables for electricity consumption for both the Sheffield samples and for the combined dataset. This is a particularly interesting result as it may be indicative of the ability of respondents' main heating systems to provide their required levels of thermal comfort and/or be indicative of changes in the way householders are heating their dwellings. In light of the strength of the number of bedrooms as an explanatory variable for energy consumption it was interesting to note that of the 46 respondents reporting using one or more portable electric heaters 20 (43%) reported using secondary heating in bedrooms. However, these statistics are not directly comparable since the question requesting where secondary heating was in use did not differentiate between the type used in each area. In hindsight this was an error in the questionnaire.

Of the respondents in the combined dataset 79% reported using some form of secondary heating, of which 74% reported use in living / dining areas, with bedrooms being the second most common room in which secondary heating was in use (30%) followed by bathrooms (20%) kitchens (18%) and other areas (14%).

Boiler type

The majority of the dwellings in the three samples were reported as having 'normal/conventional' boilers, therefore combi and/or condensing boilers were grouped together. When this variable was used in the multiple regression analyses there was weak evidence of its influence on gas consumption for the dwellings in the Sheffield samples. However, this was rather tenuous and it is the last variable to appear in these tables.

Cooker type

For cooker type the matched datasets contained only those respondents reporting gas cookers, electric cookers, or gas hobs with electric ovens. The only statistically significant correlation for cooker type was with electricity consumption for the Sheffield semis. Adding this variable to the multiple regressions with electricity consumption and the five key variables for this group confirmed that this result was highly statistically significant, and when repeated for both the Leicester terraces and the detached Sheffield dwellings there was also evidence of a correlation, although not statistically significant at the highest level.

Further attempts were made to improve on the accuracy of these results by coding as dummy variables rather than assessing the strength of the relationship with the values used as the basic coding system. This approach split the single variable into three (for the three cooker types) with binary outcomes, all of which were entered into each regression, however this produced no notable improvements.

Appliance ownership and use

There was some evidence of a correlation with electricity consumption found for dishwasher ownership in the Sheffield detached sample (Table 8.9) however this was weak and no correlations were found with the use of these appliances.

There was also some evidence of a correlation with washing machine use for the Sheffield semis, however this was the sample for which the greatest difficulties were encountered in producing the table of explanatory variables for electricity consumption. This was due to the introduction of the variables lower down in the table reducing the number of records being analysed and affecting the statistics for other variables.

One such variable was the number of full meals cooked per week. This does not appear in any of the final tables but the analyses behind them suggested weak correlations with electricity consumption for both the Sheffield samples. A similar case was the number of showers per week, which appears in the table of explanatory variables for electricity consumption for the combined dataset. As discussed in the methodology in hindsight there was an omission in the questionnaire regarding showers in that there should have been a supplementary question to differentiate between electric-instant and gas-fuelled power showers.

The frequencies of washing machine use, showering and cooking are indirect measures of differences in domestic energy consumption that can be expected to be indicative of differences in household composition and energy regimes. Clearly within the limits of these datasets their influences are being obfuscated by other factors and probably also the sensitivity of the analytical techniques.

The correlations found with electricity consumption for TV, PC and digibox ownership for the Sheffield samples and the combined dataset may also be indicative of underlying relationships influencing differences in domestic electricity consumption. In this case it was possible to use the data for PC and digibox ownership to explore this further, as described in the next chapter.

8.7.2. Summary of those variables for which no correlations with energy consumption were found

In theory all the variables in the datasets can be expected to have some influence on domestic energy consumption, however in many cases no statistical evidence of correlations with either gas or electricity consumption were found. This is most likely due to the size of the datasets, and to a lesser extent the sensitivity of the statistical techniques used to analyse them. The following is a list of those variables and a brief discussion of some of the more disappointing results from the study.

Dwelling construction

- Habitable floors.
- Cellars and basements.
- Wall construction.
- Roof type.
- Boarding and cladding.
- Loft insulation.
- Window frames.
- Extensions.
- Number of open chimneys.

Space and water heating

- Gas fuelled ducted warm air systems.
- TRVs.
- Extent of main heating.
- Thermostat temperature settings.
- Zoned heating.
- Secondary heating, other than gas fires and electric heaters.

- Use secondary heating by room.
- Water heating systems, other than boiler type.
- Boiler age, service history.
- Cylinder size and jacket type.

Appliance ownership and use

- Cold appliance ownership.
- 'Frost-free' freezers.
- Washing machines connected to hot water supply.
- Washer-dryers and frequency of use.
- Appliances purchased before/after Jan 1st 1995 and energy efficiency ratings of those purchased after[9].
- Drying clothes outdoors in warm weather.
- Frequency of tumble dryer and dishwasher use.
- Baths per week.
- Microwaves, including power and frequency of use.
- Type and maximum screen size of TVs in use.

Miscellaneous variables

- Mechanical ventilation.
- Energy efficient light bulbs.
- Solar thermal, solar PV, micro-wind and micro-CHP.
- Energy efficiency grants received.

[9] Several attempts were made to group or rate dwellings using the ownership, purchase date and energy efficiency rating data. The most promising was a simple weighting based on the number of cold and wet appliances purchased after Jan 1st 1995 for which energy efficiency ratings were reported as a percentage of the total owned by each respondent. However, this failed to yield any statistically significant results.

Socio-demographic data

- Employment by full-time, part-time, full-time education or retired.
- Socio-economic classification using Approximated Social Grade (ASG).
- Highest level of education attained by a member of the household.

Many of the variables listed here are known or can be expected to have a measurable influence on domestic energy consumption. In most cases no correlations were found due to lack of reporting (e.g. zoned heating) or because all or most respondents gave the same answer (e.g. wall construction and extent of main heating).

An example of one of these variables was tenure, for which there was some evidence of correlations between energy consumption and TFA within tenure groups (Appendix 7). Three of these correlations were with gas consumption (Leicester, owner-occupied, owned outright; Leicester all-rented; Sheffield detached) and one with electricity consumption (Leicester, all-rented). For the records matched with TFA and consumption data the Leicester terraces were the only sample for which rented properties were reported (10 dwellings, all matched with electricity consumption, 8 matched with gas consumption) therefore it was difficult to conclude anything from this. As tenure is not an appropriate variable for use in regression it was not possible to draw any further conclusions as to its influence on energy consumption within the limits of these datasets.

Some variables, such as appliance energy efficiency ratings and cooker type, were modified or combined with other variables to try and produce better measures of how they differed between dwellings. However, with the exception of those results already discussed none of these attempts proved fruitful.

The most disappointing results were the lack of any statistically significant correlations with the socio-demographic data. For employment there were a wide range of combinations of occupancy in terms of those in full-time and part-time employment, full-time education and retired persons that complicated the processing of these data.

For ASG the lack of a correlation can be explained by the strong bias towards respondents falling into either the 'AB' category (45% of the combined dataset) or being retired (36% of the combined dataset) which is not classified under the ASG system. A further 14 respondents (9% of the combined dataset) declined to answer this question.

For education there was a strong bias towards respondents having spent time in higher education, with 26% of those in the combined dataset having degrees and an additional 36% having higher degrees. As mentioned in section X there was also a level of uncertainty over which order to rank some qualifications (e.g. professional qualifications) but this problem was outweighed by the bias in the data.

8.8. Chapter Summary

This chapter has covered the results of the analyses for all of the data from the questionnaires that were matched with both floor area and annual consumption data. Many of the results are unsurprising, for example the inability to differentiate energy consumption of dwellings with different levels of loft insulation or that homeworkers were found to be significantly higher energy consumers, although the latter was not found to be covered in previously published work.

In terms of informing the development of future energy studies the most important result is the consistently high level of the significance of the number of bedrooms as an explanatory variable. Whilst most previous studies have looked at the number of rooms as a key variable this was found to be less significant than the number of bedrooms in virtually all the analyses (sections 6.4, 7.7 and 8.5). Furthermore, different studies have used different definitions of the numbers of rooms in dwellings, whilst the number of bedrooms is far easier to define. With the exception of a small number of dwelling types, e.g. studio flats, reporting the number bedrooms to does not suffer from problems such as uncertainty over whether or not to report two partially separated rooms, e.g. semi-open plan living/dining areas, as one or two rooms. The number of bedrooms also sets an upper limit on occupancy which is useful for accounting for the impact of households moving during a study. Finally, the strength of the significance combined with the evidence from other results suggests that the way occupants use bedrooms may be changing. As well as the use of spare bedrooms for home offices there may be a trend towards occupants having increasing numbers of appliances in their bedrooms and thus using and heating them for longer, although further work is needed to confirm this. Whether or not the high significance of this variable is something that has simply been overlooked in previous studies or whether it has risen to significance due to changes in underlying factors remains unclear, however these results strongly support the case for its inclusion in future studies.

The final stage of multiple regression analysis is a useful representation of the complexities involved in determining the most important of the minor factors influencing differences in domestic energy consumption. However, despite these complexities and the limitations of the datasets it was till possible to extract sets of variables for which the strongest and most statistically significant correlations with energy consumption were found.

Chapter 9. Further Analyses of Domestic Electricity Consumption and an Example Application

9. Introduction

This chapter describes to results of two further analyses conducted using the available electricity consumption data.

The multiple regression analyses used to produce tables of the variables found to have the strongest and most statistically significant correlations with electricity consumption (section 7.7) included three variables (TV, PC and digibox ownership) that are particularly to recent changes in the uptake of new technology by households in the UK (section 2.2.7). To determine whether this could be related to differences in domestic electricity consumption using the available data two step clustering was used to identify groups of technology consumers within the combined dataset. This led to the discovery of three clusters within the data which were correlated with the electricity consumption data and also crosstabulated with the socio-demographic data to further elucidate their composition by household type. These results are presented in section 9.1.

The electricity consumption data was analysed in relation to TFA and occupancy using a version of the BREDEM lights and appliances sub-model (common to all BREDEM models) implemented in Excel spreadsheet format by Dr. Steven Firth of the IESD. These equations were then modified using the adjustments for energy efficient light bulbs and cookers to determine the extent to which the predictions could be improved. This also provides an example of how these findings could be used to improve existing energy ratings and models, especially if the conclusions drawn are further substantiated by future studies. The methodology and results for these analyses are given in sections 9.3.

9.1. TVs, PCs and technology uptake

As a result of finding some evidence of correlations between electricity consumption and the number of TVs and PCs in use[10] by respondents as part of the multiple regression analyses these variables were analysed in more detail and used to attempt to develop an indicator common to electricity consumption across all the datasets.

The summary results for the correlations of TV and PC ownership and use are given in Tables 9.1 and 9.2. These show the Spearman correlations for these variables with the banded electricity data, the Pearson correlations and ANOVA significance values for multiple regressions against the electricity, initially with the inclusion of TFA and occupancy, and then with dwelling age and the numbers of rooms and bedrooms added.

It is useful to compare these two tables as many of the correlations and significance values are similar, suggesting some underlying relationships or factors are present relating to the ownership and use of these devices.

Table 9.1. Significance of number of TVs as an explanatory variable for electricity consumption

Variable, correlation, and significance test	Study Area			
	Leicester terraces	Sheffield Detached	Sheffield Semis	Combined datasets
Spearman Correlation with banded electricity data	0.281	0.223	0.371	0.292
Approx. significance of SC with banded electricity data	0.048	0.141	0.007	0.000
Pearson correlation for multiple regressions with TFA and TotOcc	0.173	0.193	0.330	0.261
ANOVA significance of multiple regressions with TFA and TotOcc	0.005	0.007	0.011	0.000
Pearson correlation for multiple regressions with TFA, TotOcc, Age, No Rooms and No. Bedrooms	0.095	0.235	0.323	0.275
ANOVA significance of multiple regressions with TFA, TotOcc, Age, No Rooms and No. Bedrooms	0.061	0.034	0.000	0.000

[10] The questionnaire specifies that the numbers reported must be in regular use

Table 9.2. Significance of number of PCs as an explanatory variable for electricity consumption

	Study area			
Variable, correlation and significance test	Leicester terraces	Sheffield Detached	Sheffield Semis	Combined datasets
Spearman Correlation with banded consumption data	0.332	0.415	0.333	0.399
Approx. significance of SC with banded data	0.034	0.004	0.018	0.000
Pearson correlation for multiple regressions with TFA and TotOcc	0.289	0.397	0.389	0.340
ANOVA significance of multiple regressions with TFA and TotOcc	0.001	0.004	0.004	0.000
Pearson correlation for multiple regressions with TFA, TotOcc, Age, No Rooms and No. Bedrooms	0.256	0.401	0.390	0.343
ANOVA significance of multiple regressions with TFA, TotOcc, Age, No Rooms and No. Bedrooms	0.008	0.024	0.000	0.000

The results for the 8 multiple regressions show that the correlations are all highly significant, and although correlations were found with all the variables other than age there was no statistically significant level of collinearity in any of the analyses. The most consistent and significant evidence for a correlation between either of these variables and those already accounted for was between TV ownership and occupancy.

The correlations are marginally, but consistently, stronger and more significant with PCs than with TVs. Although these correlations are relatively weak, in the context of other stronger results that largely conform to expectations it is at least justifiable to infer that these factors could form part of a sub-model of domestic electricity consumption more sophisticated than is currently typical in UK energy models. This would require further confirmatory work on a sufficiently large dataset and a revised sampling strategy to focus more specifically on these factors. Even so, the work described here is used to demonstrate how such findings could be applied in this context (section 9.2).

As most UK households own at least one TV, higher levels of ownership may be indicative of households with larger numbers of occupants, living in larger dwellings with more rooms and bedrooms spending more time at home watching

TV. However, PC ownership and use may also be indicative of the wider use of technology by householders, and to an extent it was possible to substantiate this by further analysis of the datasets.

To produce an indicator of the level of technology uptake by households and determine if this could be used to help explain differences in electricity consumption two additional variables were analysed, these being broadband access and ownership and use of digiboxes. The latter was selected as being a potentially useful indicator of technology consumption given that the UK is in the process of switching to digital TV. When entered into multiple regression analyses in combination with other variables both had produced some evidence of correlations with electricity consumption, although this was relatively minor and insignificant. Therefore the aim here was to assess their cumulative statistical significance in improving the regression model.

The number of PCs owned was first crosstabulated with broadband access, and in all cases the correlations were highly statistically significant (using the 2-sided asymptotic significance test for the Likelihood ratio) with the highest levels of significance being for the results for the combined datasets. Broadband access is treated as approximately ordinal, being either 'no access', 'dial up' or 'always on'. The results for these correlations are given in Table 9.3, higher likelihood ratios are indicative of stronger correlations but the significance value is more important than the ratio itself (SPSS definition).

Table 9.3. Correlations between the number of PCs owned and broadband access

	Leicester terraces	Sheffield detached	Sheffield semis	Combined dataset
Likelihood ratio	15.216	28.649	20.867	49.068
Asymp. Sig. (2-sided)	0.019	0.000	0.008	0.000

These results confirmed the expectation that there was a clear relationship between higher levels of PC ownership and broadband access within the datasets.

Two step clustering was then used to determine if distinct groups of technology users existed within the data that could be determined using the three variables. In order to maximise the number of clusters produced this was performed only on the combined datasets and the composition of these clusters is given in Table 9.4. This table shows the three clusters produced, representing households with relatively distinct differences in technology ownership and use, subsequently referred to as 'technology uptake', ranging from those with low levels of uptake in cluster 1 to high levels of uptake in cluster 3.

Table 9.4. Composition of clusters for technology uptake by technology

	No.	PCs	Digiboxes	Broadband access	
Cluster 1	0	39	25	0	None
	1	0	12	5	Dial-up
	2	0	2	0	Always on
	No.	**PCs**	**Digiboxes**	**Broadband access**	
Cluster 2	0	0	0	0	None
	1	27	29	29	Dial-up
	2	0	0	0	Always on
	3	2	0		
	No.	**PCs**	**Digiboxes**	**Broadband access**	
Cluster 3	0	3	21	21	None
	1	39	27	10	Dial-up
	2	11	8	26	Always on
	3	3	1		
	4	0	0		
	5	1	0		

Cluster 1 is generalised as low technology consumers as none has a PC and the majority have yet to switch to digital TV (note that 'digiboxes' were specified as including cable/satellite boxes). The five respondents reporting dial-up access can be assumed to have laptops as the questionnaire specified that these devices were not to be reported as PCs. Cluster 2 is composed almost entirely of respondents with one PC, one digibox and dial-up broadband access. Cluster 3 is composed of all those households with 'always on' broadband access and almost all of those reporting two or more PCs and digiboxes. Although this latter cluster does contain numbers of those in the other categories there is a clear focus on higher technology uptake.

The apparently systematic differences in the compositions of these clusters led to the treatment of the cluster numbers as values of a new approximately ordinal variable. This was crosstabulated with the banded electricity data and added to the multiple regression for electricity consumption against the five cardinal variables. The results of both analyses were highly significant.

The Spearman correlation for technology uptake crosstabulated with the banded electricity data was 0.281, with an approximated significance value of 0.002. Although this correlation is rather weak it is highly significant. As with all cluster analyses the relationship appears more evident when interpreted visually. This is illustrated by Figure 9.1 which shows the composition of the clusters by the banded electricity data, in which the trend in high energy use bands is clear, though that in low use bands is less so, and Figure 9.2 which shows the composition of the bands by the clusters, in which quite clear trends in technology uptake are visible, with some breakdown around band 2.

Furthermore, when added to the multiple regression of electricity consumption data with the five most statistically significant variables the results showed that the correlation was improved at the highest level of statistical significance (significance of the F statistic change was 0.025). The Pearson correlation with electricity consumption was 0.283 and the overall ANOVA significance was 0.000.

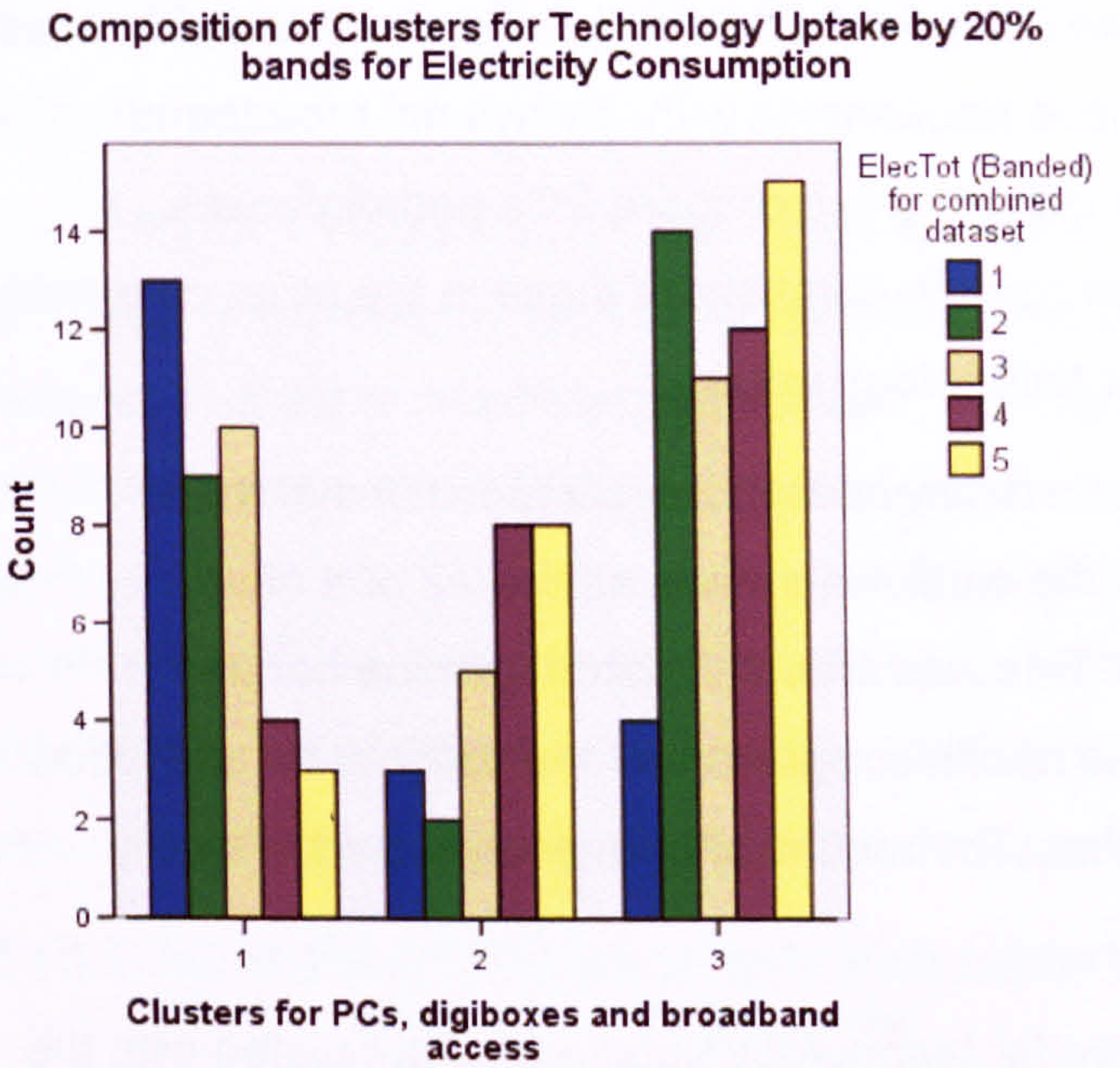


Figure 9.1. Composition of clusters for technology uptake by 20% bands for electricity consumption

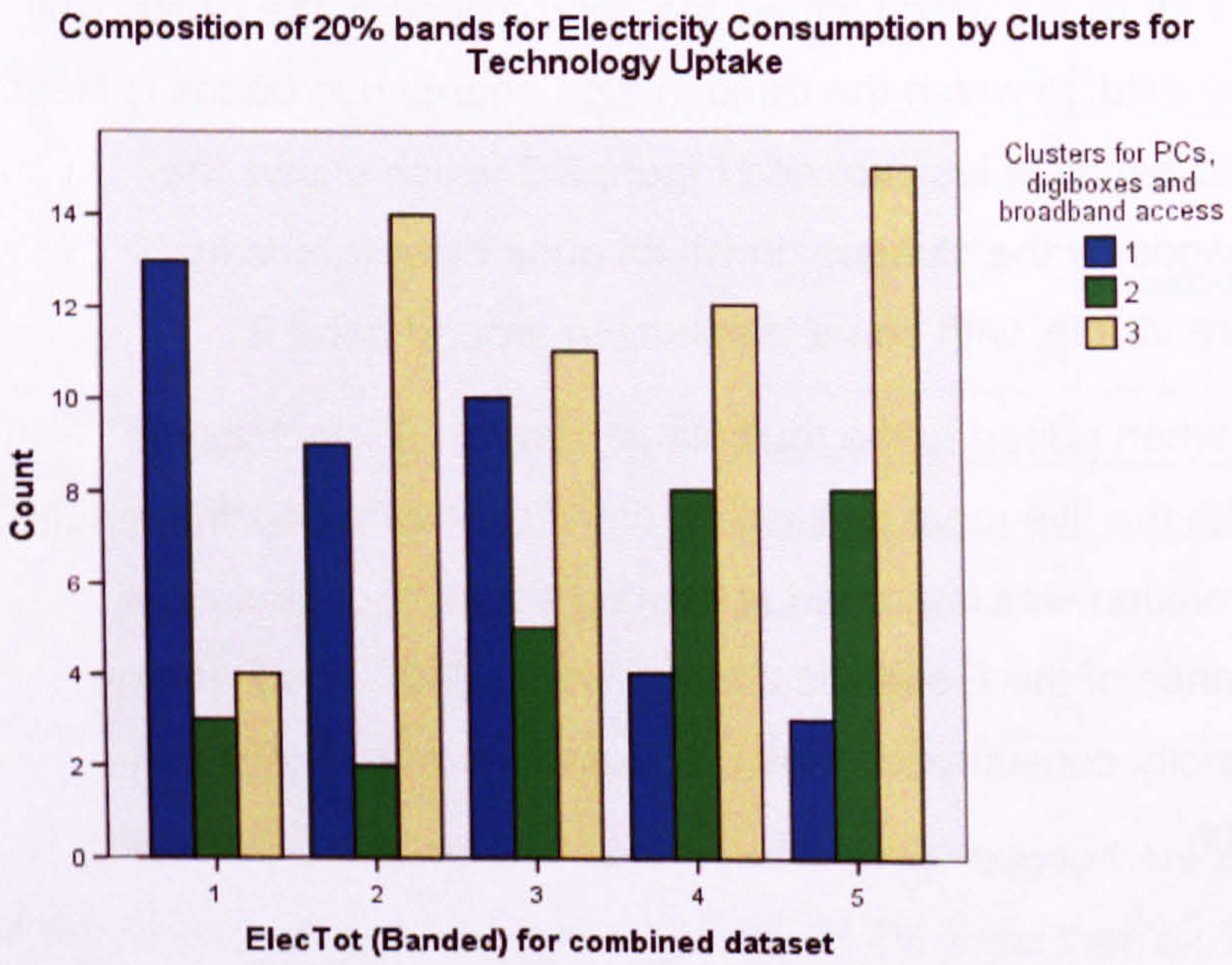


Figure 9.2. Composition of 20% bands for electricity consumption by clusters for technology uptake

This new variable is an indirect indicator of differences in domestic energy consumption and as such it was necessary to assess whether or not it could be related to other variables in the dataset. Of particular interest was whether it might be a proxy for socio-demographic differences between the households in the sample. Although it was not possible to relate this to socio-economic classification due to the dominance of respondents in the 'AB' group it was possible to relate it to occupancy and education. These differences are illustrated in Figures 9.3 and 9.4.

For occupancy there is a preponderance of smaller households within cluster 2, with single or two person households typifying cluster 1. The correlation between cluster number and occupancy was also highly significant, albeit fairly weak (Spearman correlation 0.279, approximated significance 0.002). The trend towards households with 3 or more occupants in cluster 3 clearly contributes to the strength and significance of this correlation, although this does confirm the expectation that households with larger numbers of occupants tend to be higher consumers of technology.

There was also some relationship with the highest level of education attained by a member of the household, although this result has the caveat that the education categories used are not strictly ordinal (e.g. 'professional qualifications' include those such as chartered accountancy which may be considered higher than a degree). The Spearman correlation for this analysis was 0.159 and the approximated significance value was 0.08, which narrowly fails to be significant at the highest level. However, it is notable that almost all those reporting a level of education of NVQ / GNVQ or below fell into the low technology consuming cluster and that the highest level of education is characteristic of cluster 3.

It was also interesting to note that no correlation was found when the clusters were analysed for the number of households containing at least one retired person. This suggests, albeit very tentatively, that occupant age is not an indicator of technology uptake.

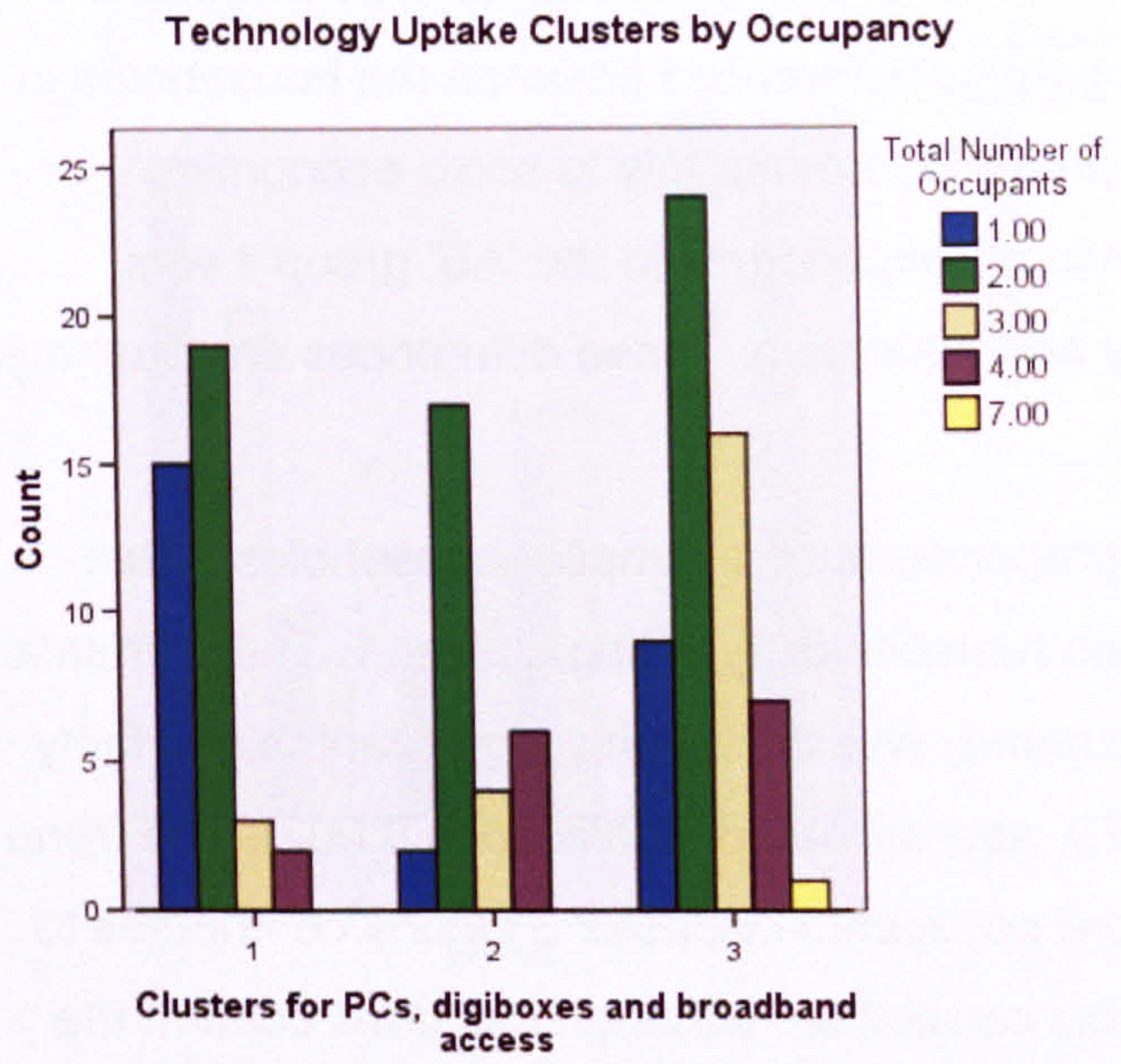


Figure 9.3. Composition the clusters for technology uptake by occupancy

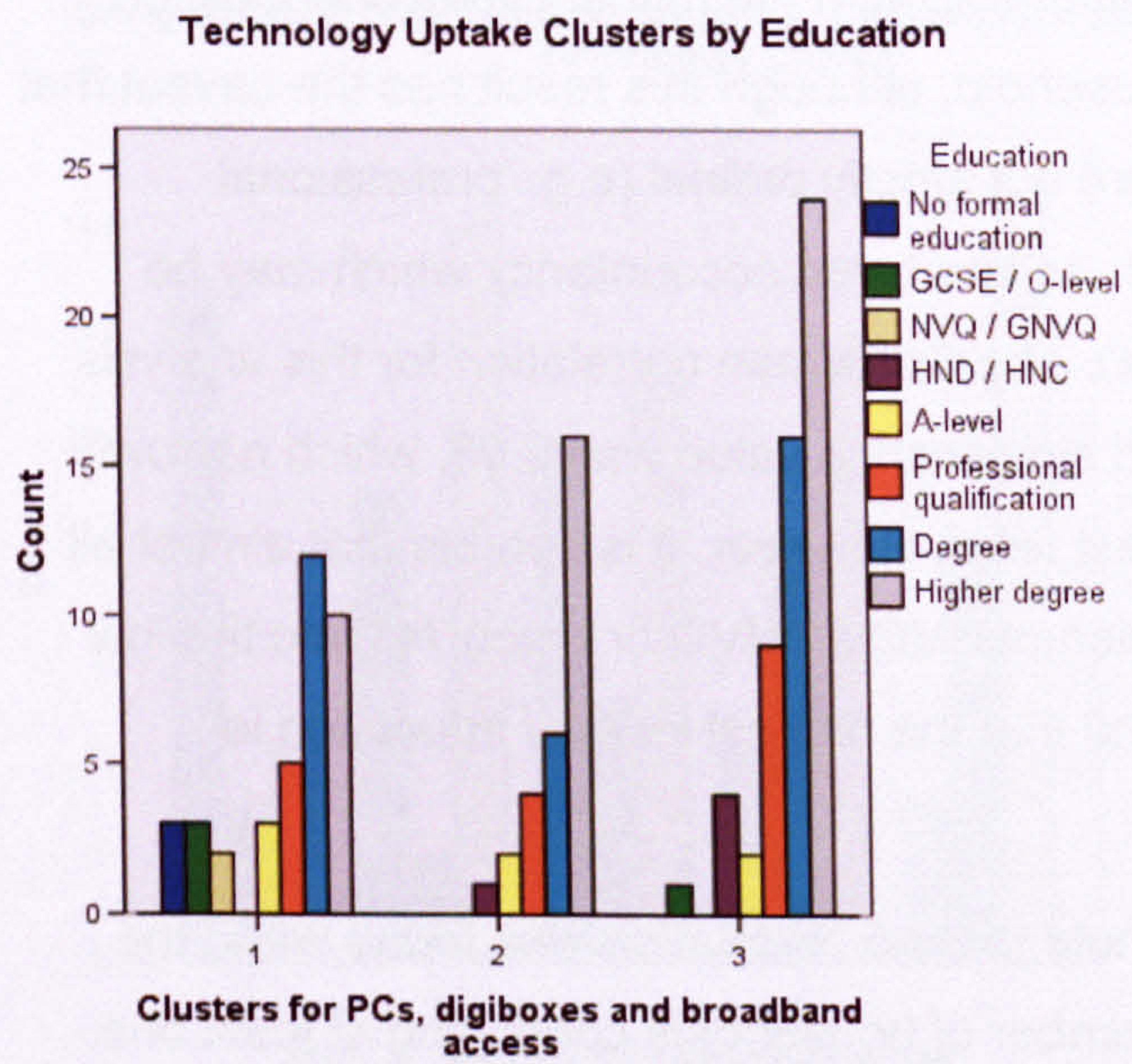


Figure 9.4. Composition the clusters for technology uptake by highest level of education attained by a member of the household

The production and significance of a variable reflecting technology uptake was an unexpected late development resulting from the attempt to further determine the suggested significance of the number of PCs in use as an explanatory variable. Its main weakness is that as a clustered variable it will require evidence from larger studies to fully ascertain whether or not the generalisations made from the composition of the clusters apply to the wider UK population. However, the amount of technology in UK homes and the ways in which it is used are changing, and if these changes are producing a significant overall increase in domestic energy consumption this will need to be accounted for in both future domestic energy models and policies relating to domestic energy consumption.

9.2. Use of the data with the BREDEM sub-model for lights and appliances

In order to assess the potential for developing the models in, for example, reduced dataset rating schemes based on domestic energy models the basic data for TFA, occupancy (N) low energy lightbulbs (LELs) and cookers was analysed using the BREDEM sub-model for electricity consumption by lights and appliances (variable denoted E_{LA}) plus the modifications for LELs and cookers (Anderson et al., 2002). This was then correlated with the measured consumption data. The basic formulae for calculating E_{LA} are as follows:

For TFA x N <710:

$$E_{LA} = 4.47 + 0.0232\ \text{TFA} \times N$$

For 710 ≤TFA x N < 2400:

$$E_{LA} = 11.98 + 0.0146\ \text{TFA} \times N - 2.78 \times 10^{-6}\ (\text{TFA} \times N)^2$$

For 2400 ≤TFA x N:

$$E_{LA} = 31.01$$

The results are in GJ/year and are converted to kWh by multiplying by 277.8.

Adjustments can be made for above, below and well below average appliance use by modifying the predictions by +20%, -20% and -40% respectively. Attempts were made to apply this weighting system using the numbers of appliances reported by respondents, however none produced results worth noting.

More notable results were produced by applying the adjustments for the number of low energy light bulbs in use, and for the types of cooker in use. These were also adjusted using data from the questionnaire to weight the results.

The proportion of LELs in use as the main form of lighting in a room is approximated using a five point (0.25 interval) scale between 0 and 1 and given a weighting of 2 for lounges, kitchens and hallways. This is then used to calculate the reduction in energy use (E_{red}) using the following formula:

$$E_{red} = 0.8 \times 0.16 \times E_{LA} \times LEL$$

As the proportion of LELs in each room was not collected by the questionnaire and as use of LELs in hallways was not questioned some simple approximations were made. The weighting of hallways was applied to dining rooms on the basis that these tend to be large fully-lit areas. The proportion of LELs was calculated first by simply dividing the number of LELs in use by the number of rooms and a second variable was produced by weighting the results for LELs in use in living rooms, dining rooms and kitchens. These were noted as the variables $E_{red}V1$ and $E_{red}V2$ and were calculated as follows:

$$E_{red}V1 = 0.8 \times 0.16 \times E_{LA} \times (\text{No. LELs / No. Rooms})$$

$$E_{red}V2 = 0.8 \times 0.16 \times E_{LA} \times [(2^*(\text{Lounge+Dining+Kitchen}) + \text{No LELs} - (\text{L+D+K}))/\text{No Rooms}]$$

The predictions can also be modified by adding the BREDEM adjustment for fuel use by cookers (E_k) as follows:

Electric: $E_k = 1.70 + 0.34\ N$

Gas: $E_k = 2.98 + 0.60\ N$

Gas hob and electric oven: $E_k = 0.85 + 0.17\ N$

E_k can also be adjusted for above, below and well below average use as for the basic E_{LA} model. This was done by calculating the mean and quartiles for the variable 'full meals cooked per week' (FMCPW) and adjusting each result using the BREDEM approximations. The resultant values are noted as the variable $AdjE_k$ and was calculated as follows:

For FMCPW above mean:

$AdjE_k = E_k + 0.2 * E_k$

For FMCPW below average (mean FMCPW > FMCPW > 0.5*mean FMCPW):

$AdjE_k = Ek - 0.2 * Ek$

For FMCPW well below average (FMCPW < 0.5*mean FMCPW):

$AdjE_k = E_k - 0.4 * E_k$

9.3.1. Results for the annual consumption data correlated with the E_{LA} predictions

The plots for the annual electricity consumption data regressed against the predicted electricity consumption using the basic E_{LA} equation are given in Figures 9.5a to 9.5d.

Adjustments for low energy lights ($E_{red}V1$ and $E_{red}V2$) produced the plots given in Figures 9.6a to 9.6d and to 9.7a to 9.7d, and the plots for which the adjustments for cooker type (E_k and $AdjE_k$) were applied to the predicted consumption figures are given in Figures 9.8a to 9.8d and to 9.9a to 9.9d.

From these analyses it was found that the best adjustment to the basic E_{LA} predictions were made using $E_{red}V1$ and $AdjE_{k:}$ the results were denoted $AdjE_{LA}$. The plots the annual electricity consumption data regressed against these predictions are given in Figures 9.10a to 9.10d.

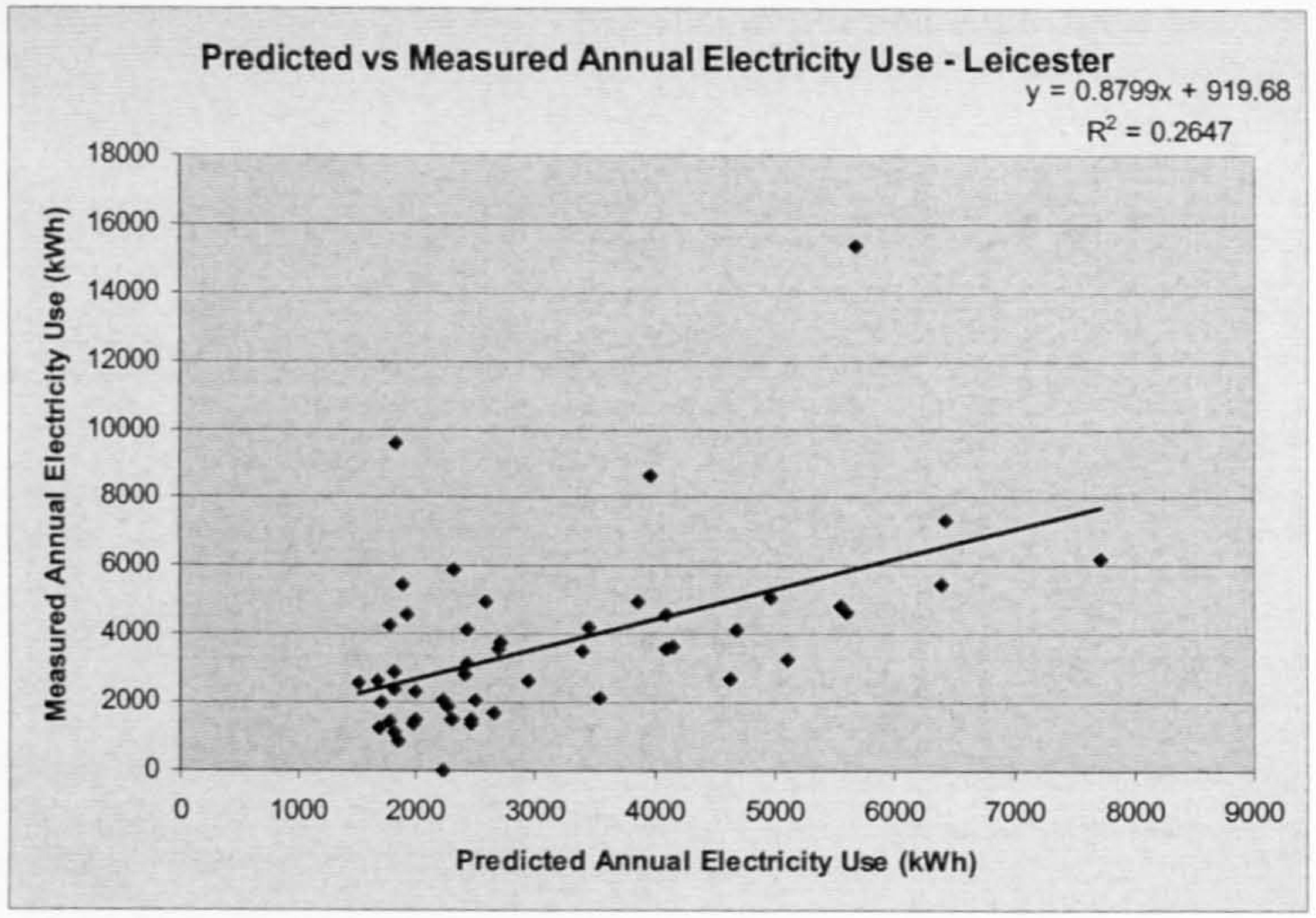


Figure 9.5a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using the basic E_{LA} equation

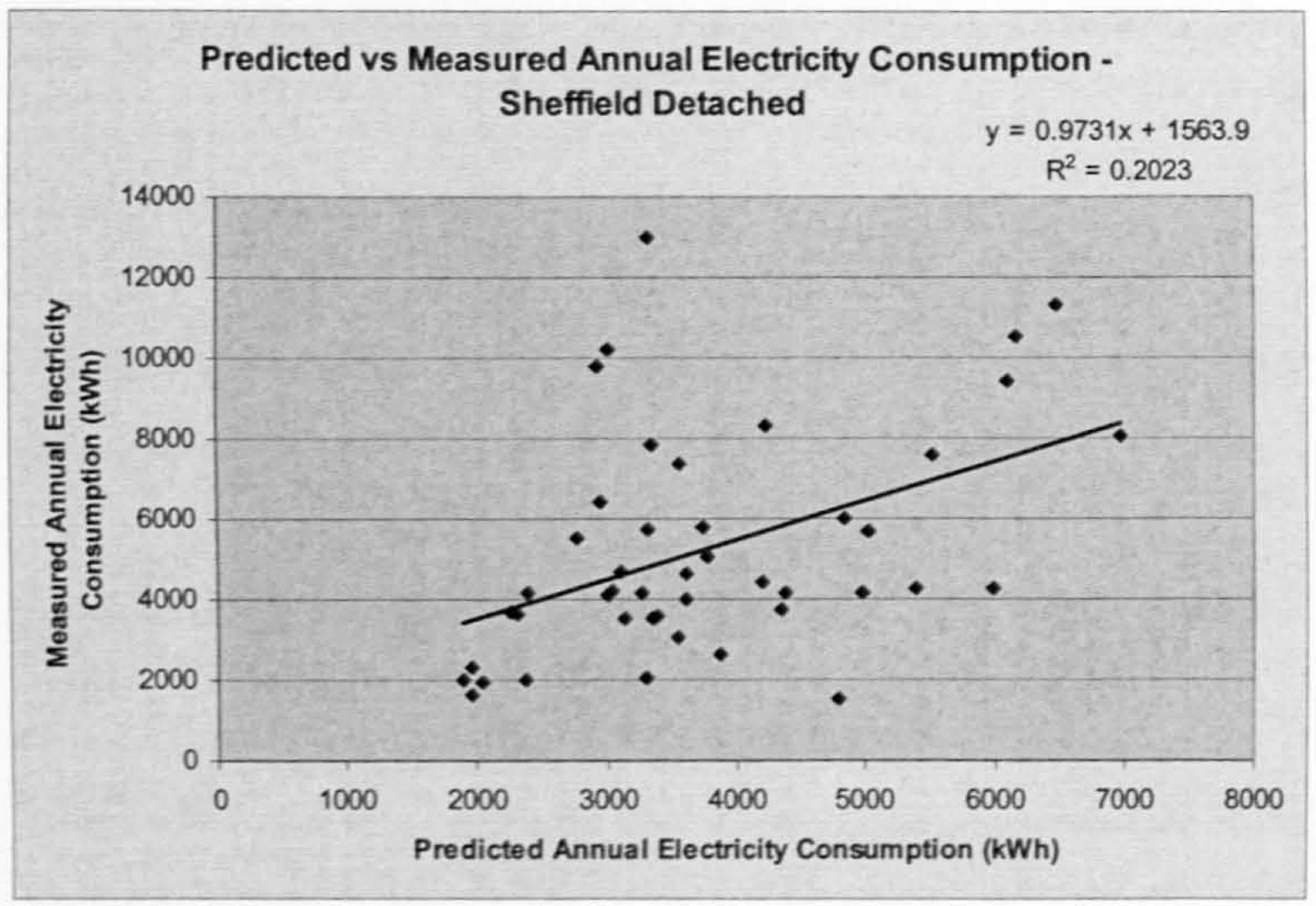


Figure 9.5b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwelings using the basic ELA equation

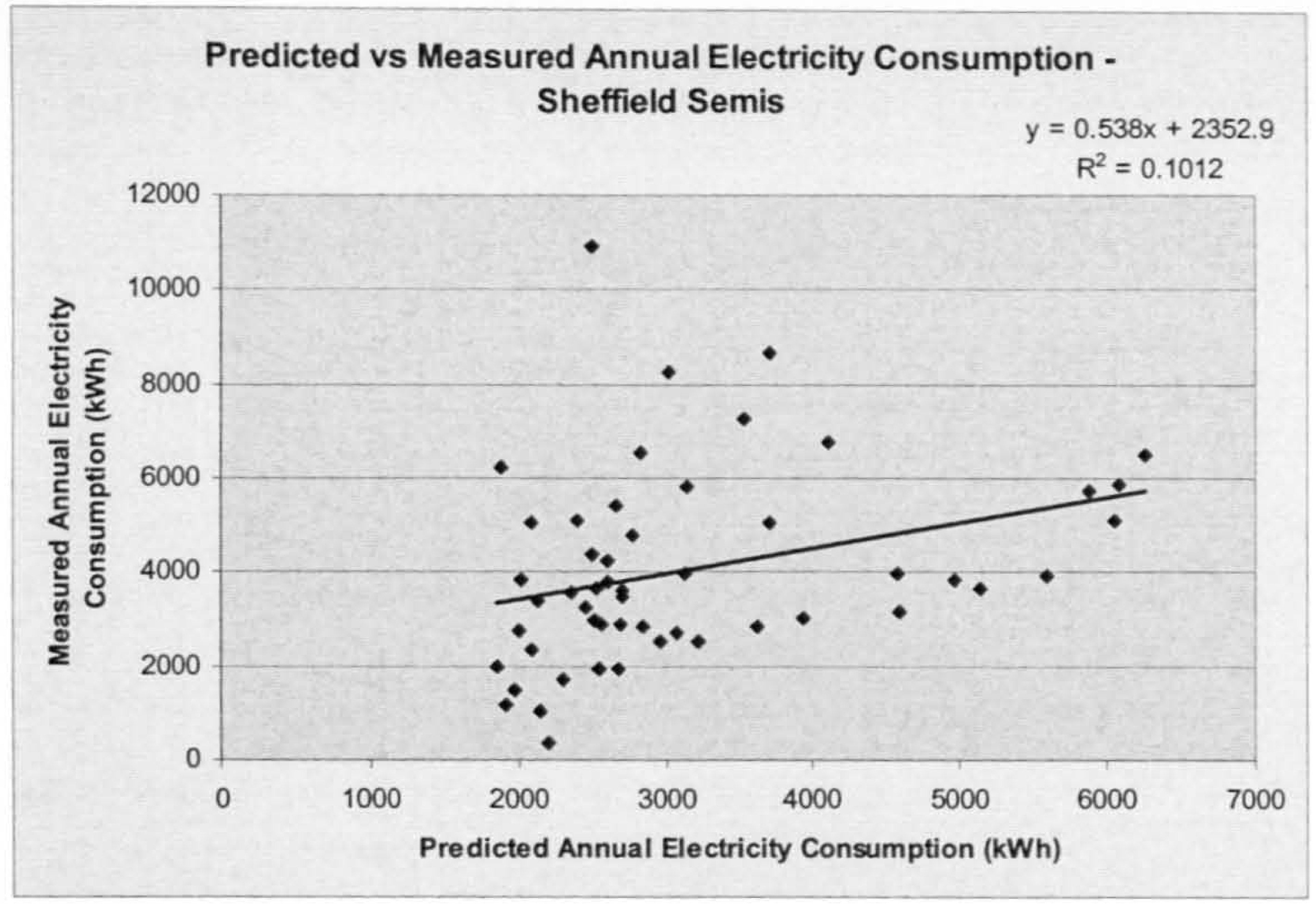


Figure 9.5c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using the basic ELA equation

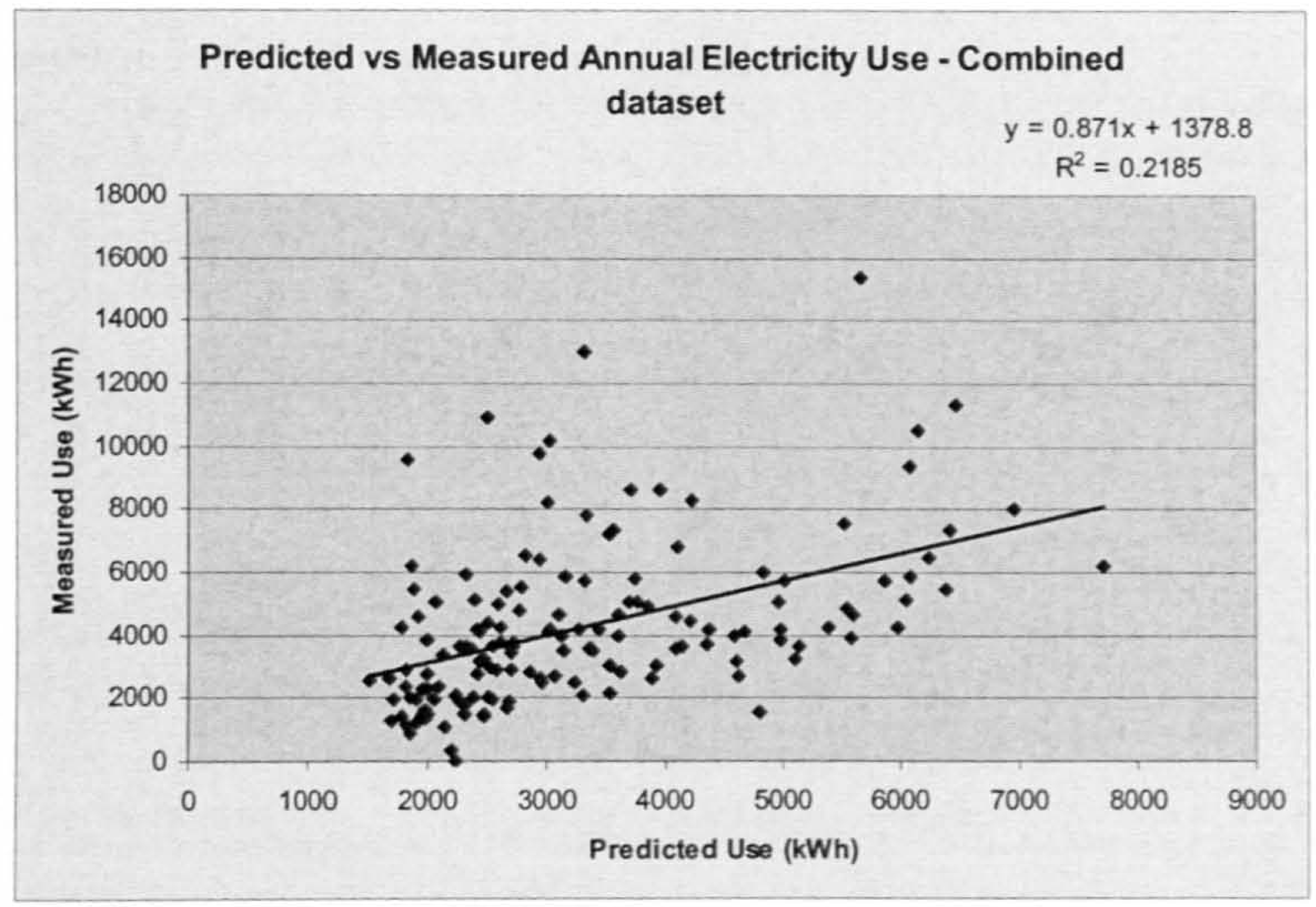


Figure 9.5d. Predicted vs Measured Annual Electricity Use for the combined dataset using the basic ELA equation

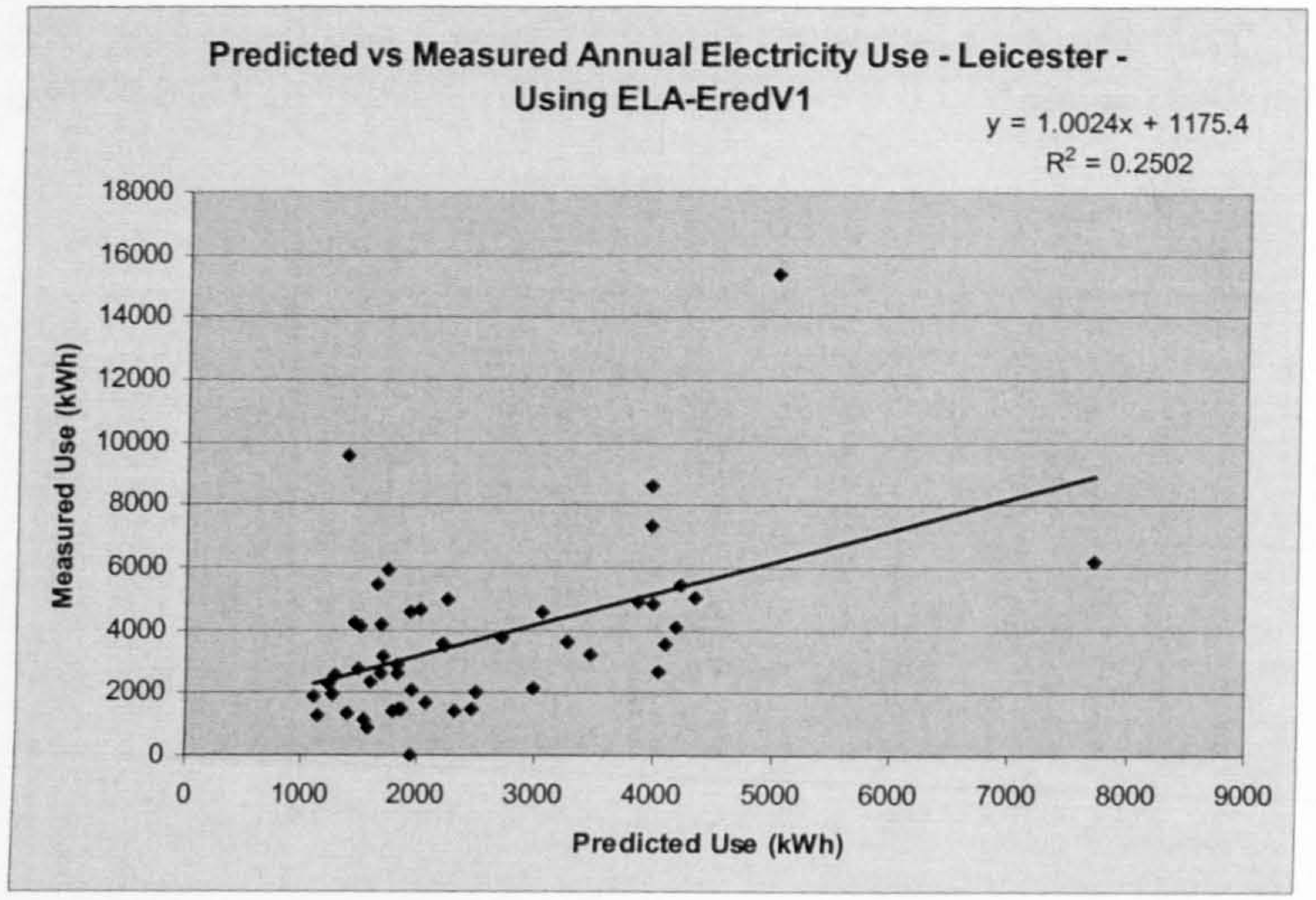


Figure 9.6a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using ELA – EredV1

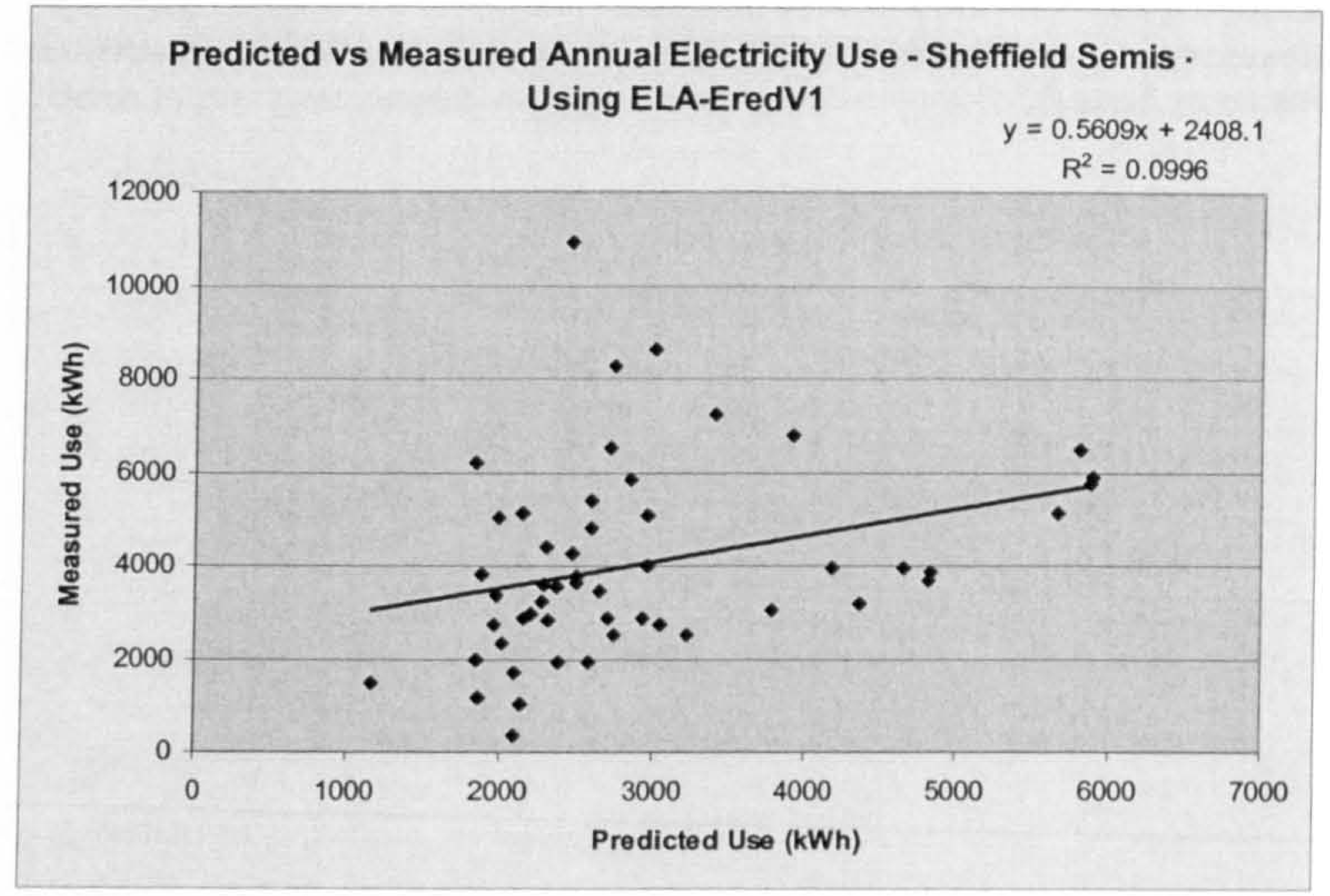


Figure 9.6c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using ELA – EredV1

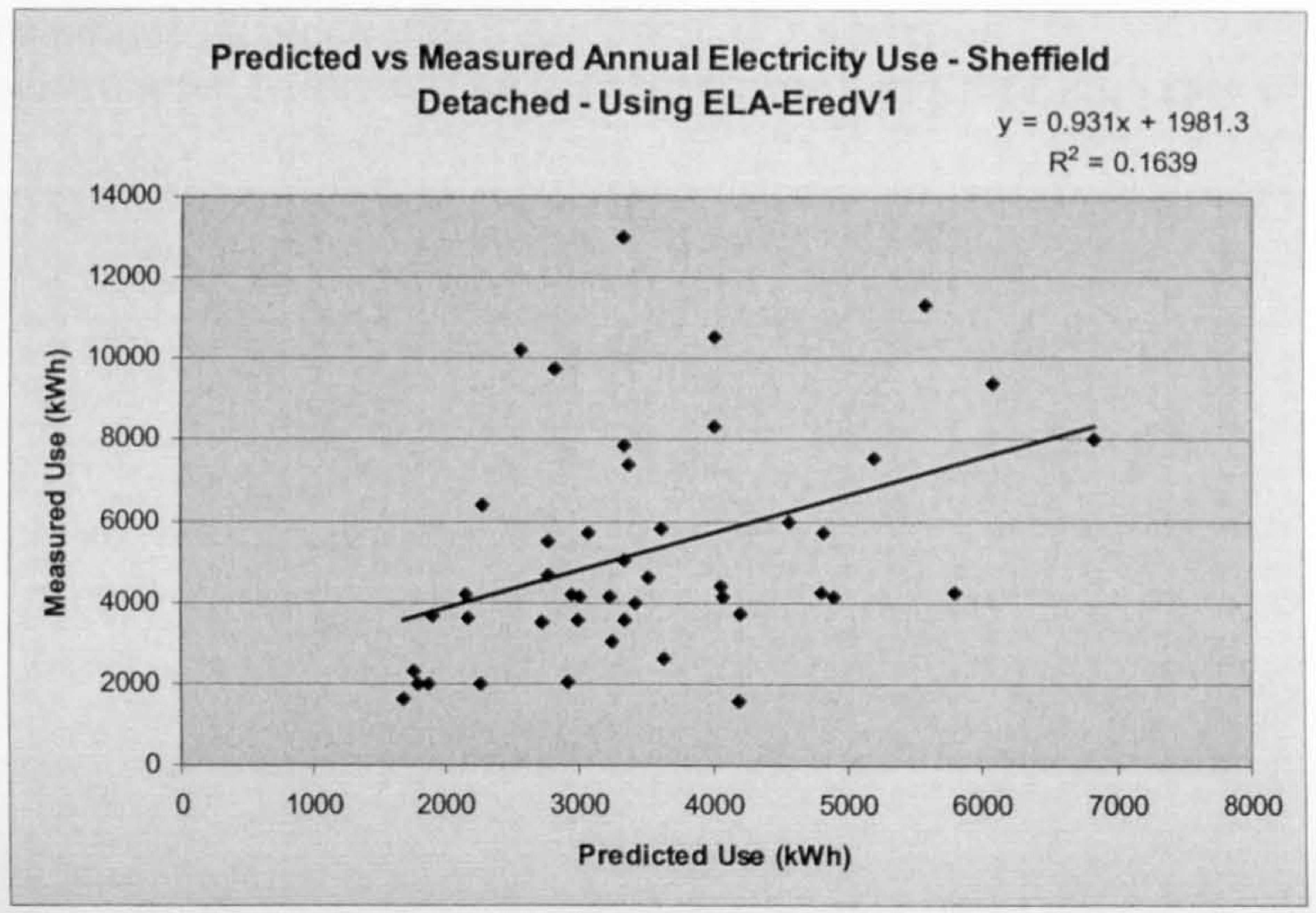


Figure 9.6b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwellings using ELA – EredV1

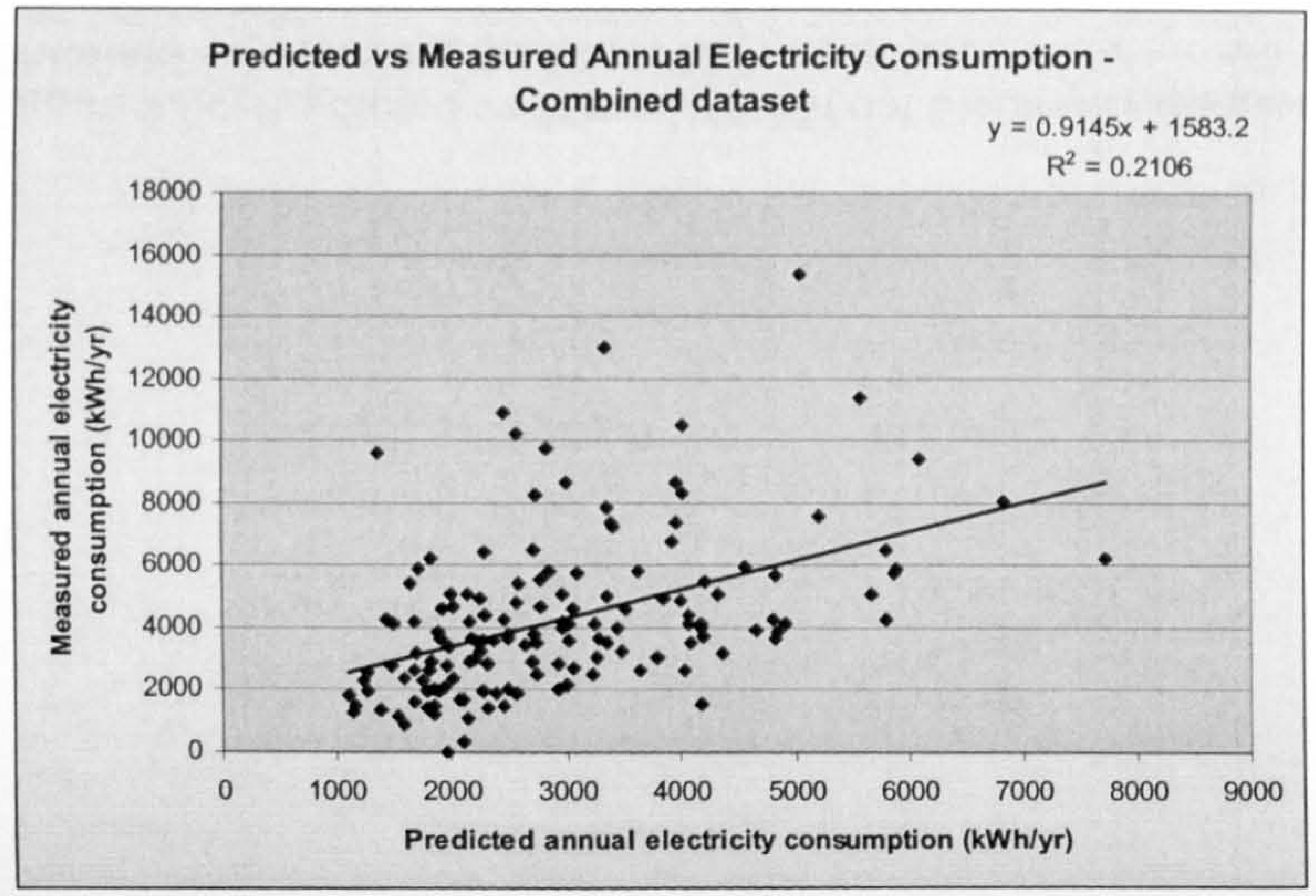


Figure 9.6d. Predicted vs Measured Annual Electricity Use for the combined dataset using ELA – EredV1

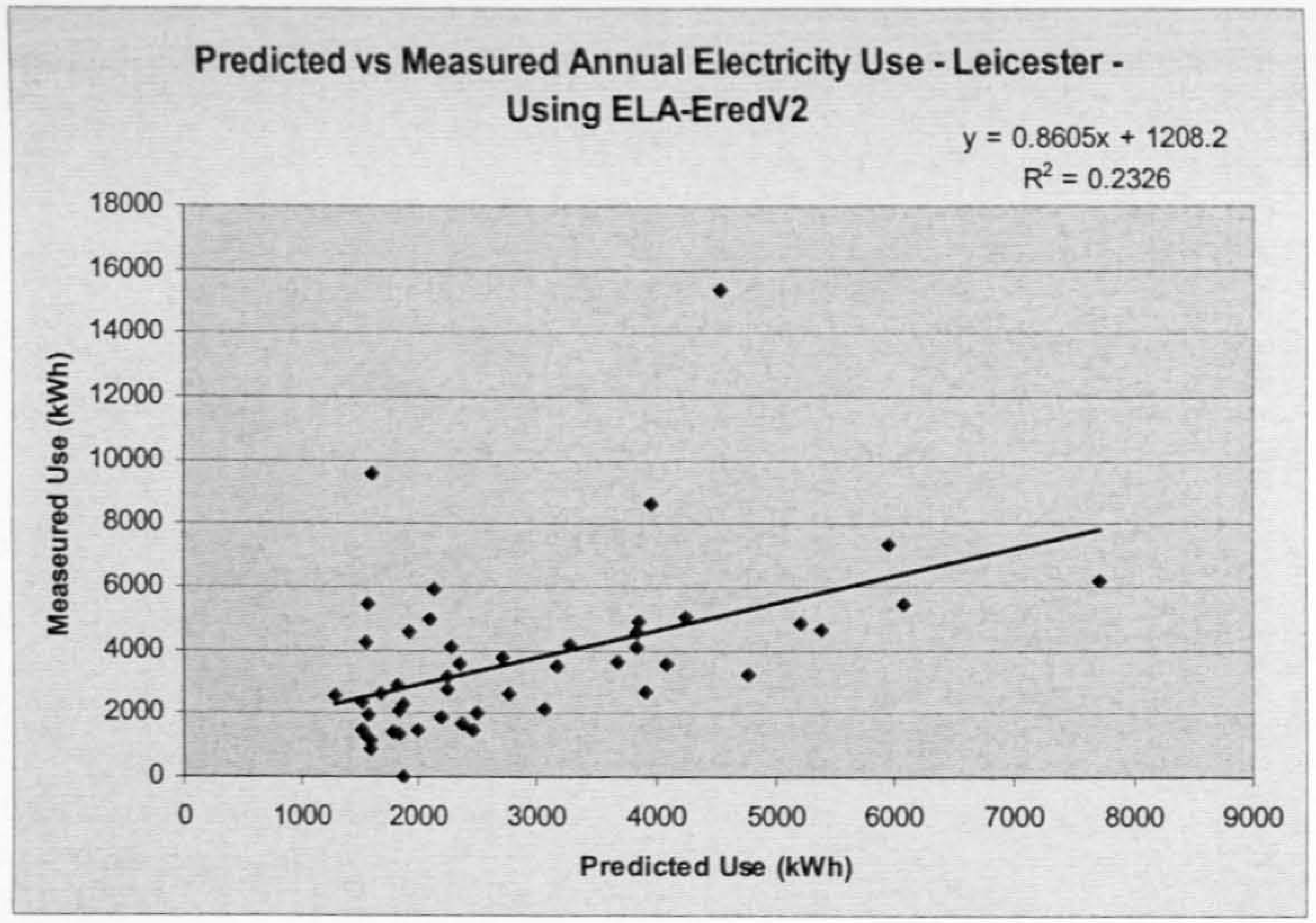


Figure 9.7a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using ELA – EredV2

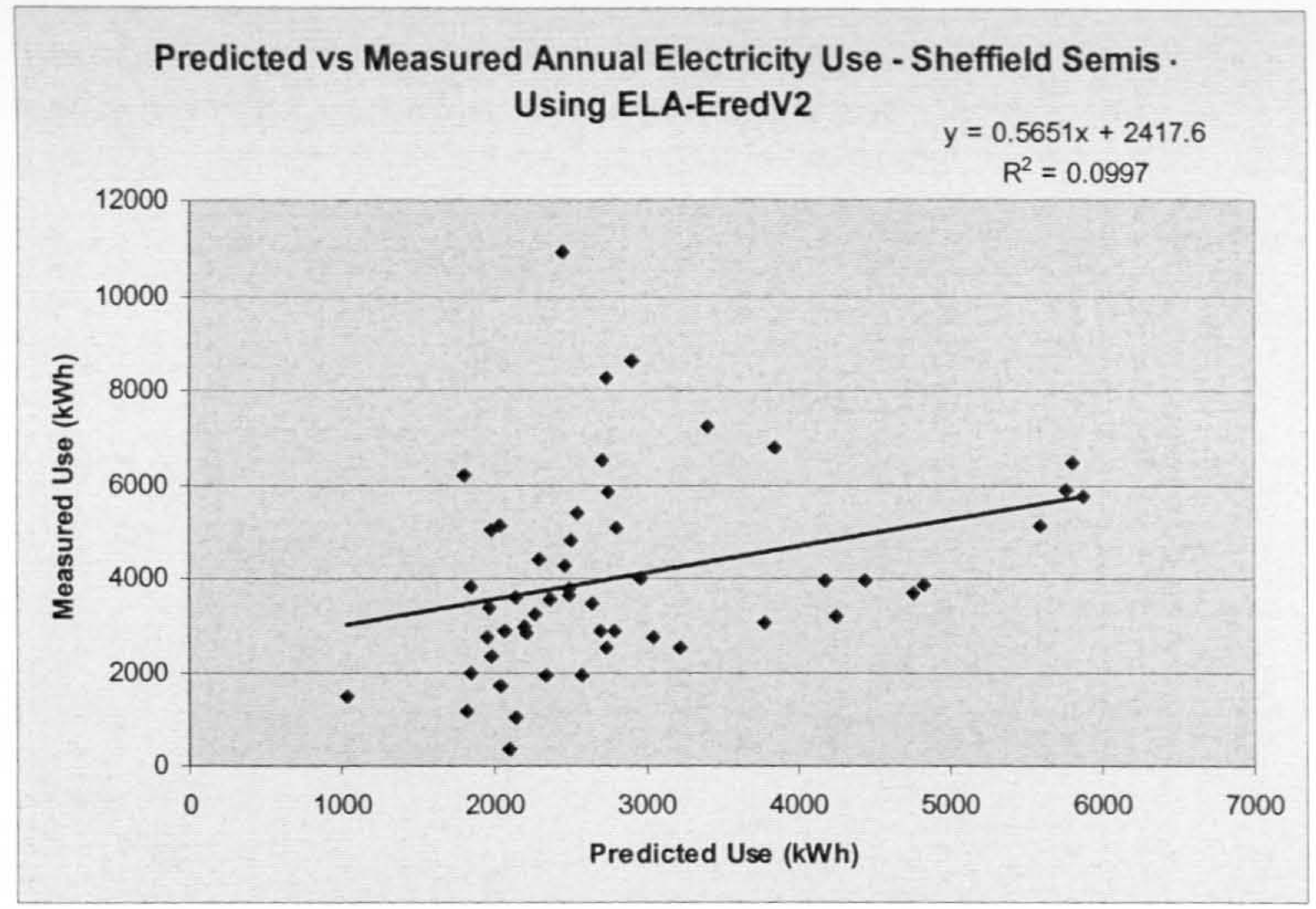


Figure 9.7c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using ELA – EredV2

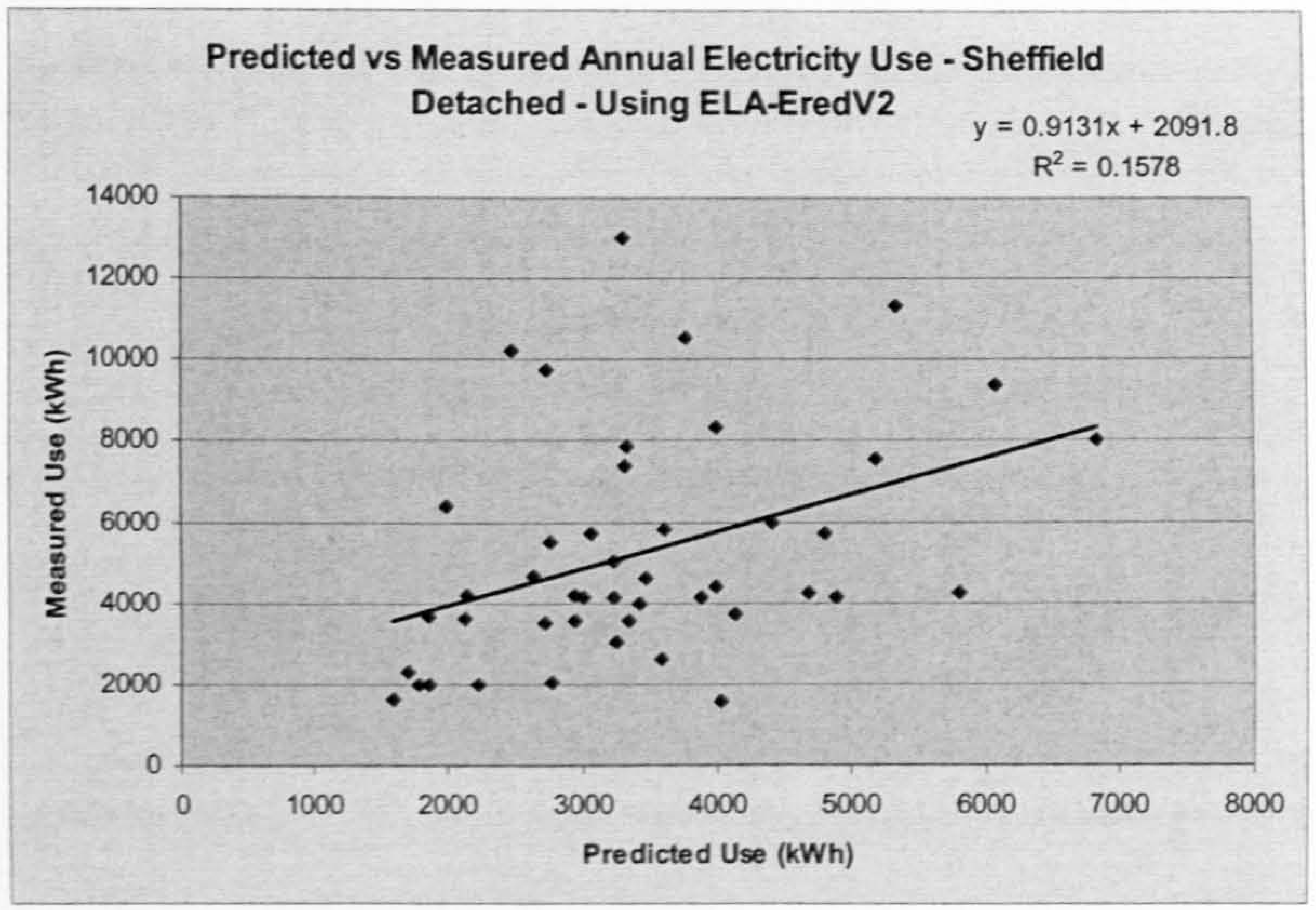


Figure 9.7b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwellings using ELA – EredV2

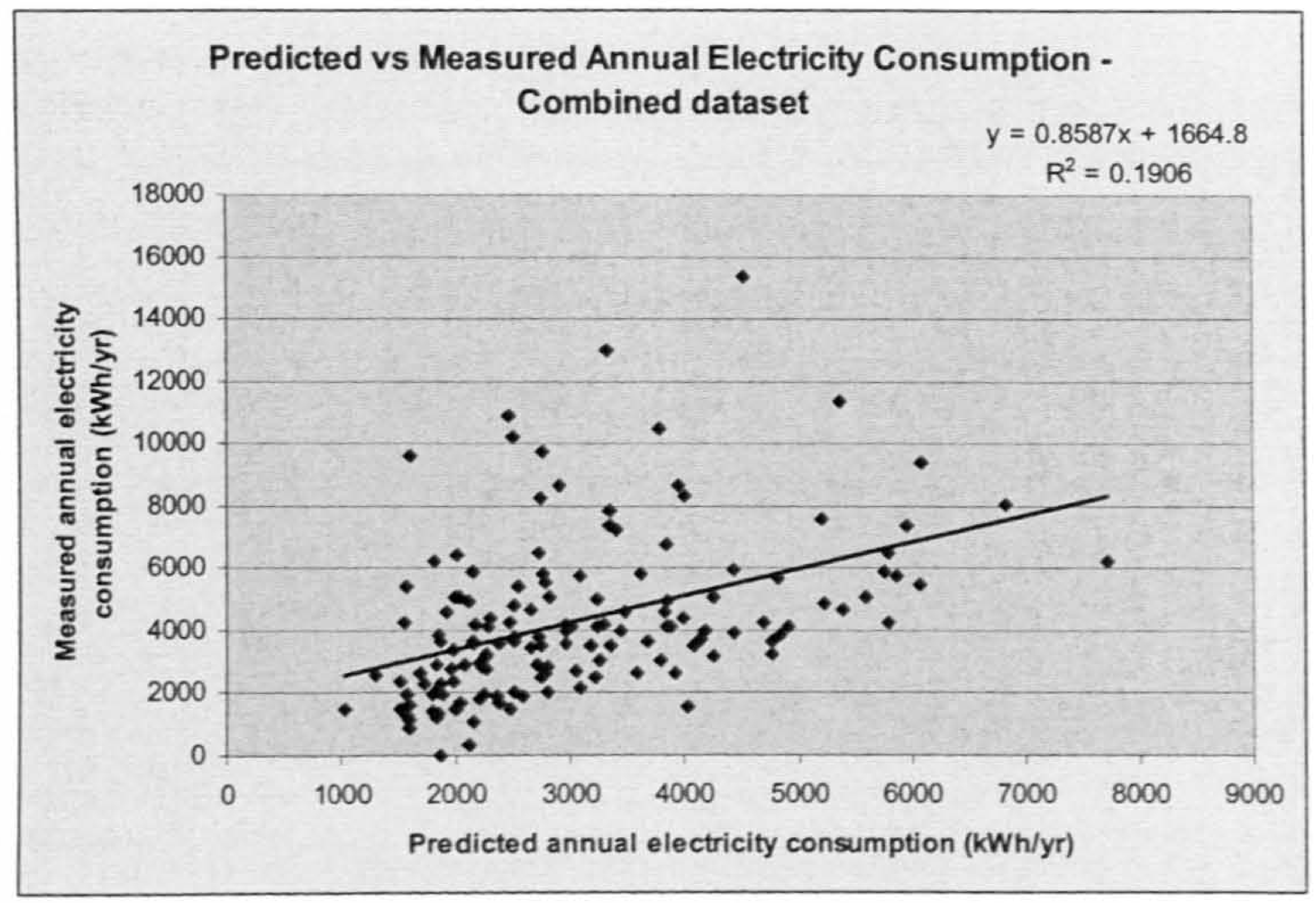


Figure 9.7d. Predicted vs Measured Annual Electricity Use for the combined dataset using ELA – EredV2

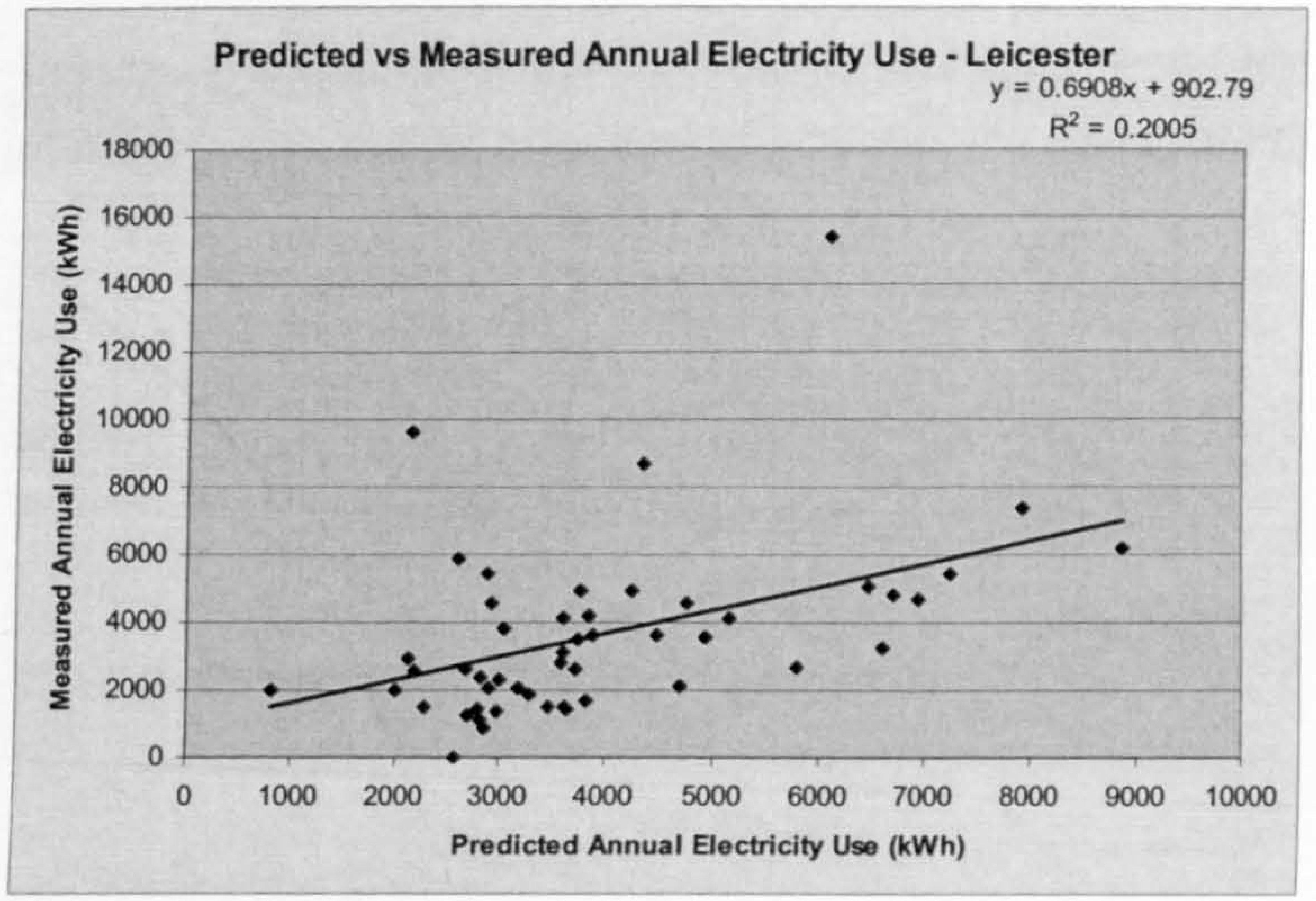


Figure 9.8a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using ELA + Ek

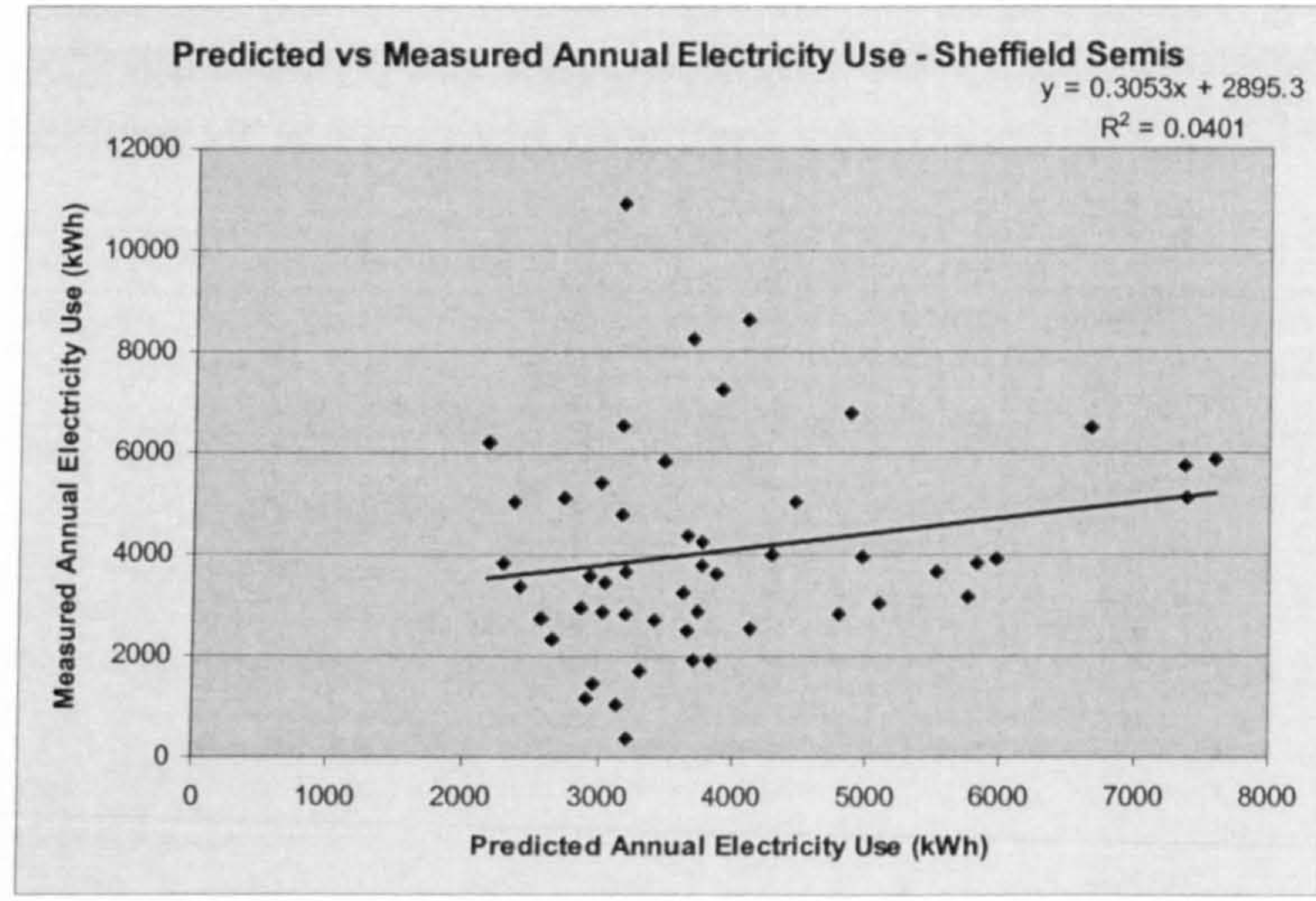


Figure 9.8c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using ELA + Ek

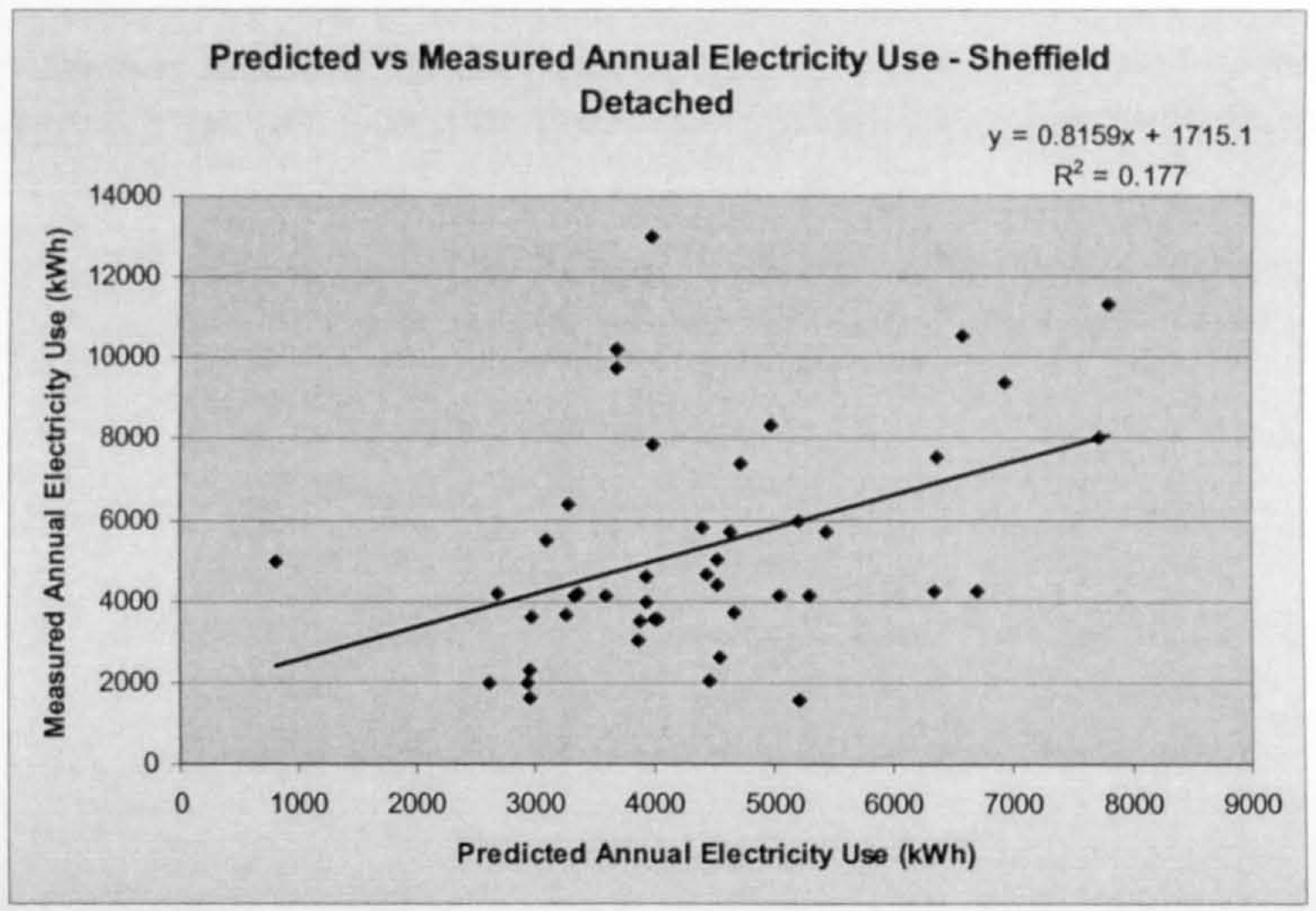


Figure 9.8b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwellings using ELA + Ek

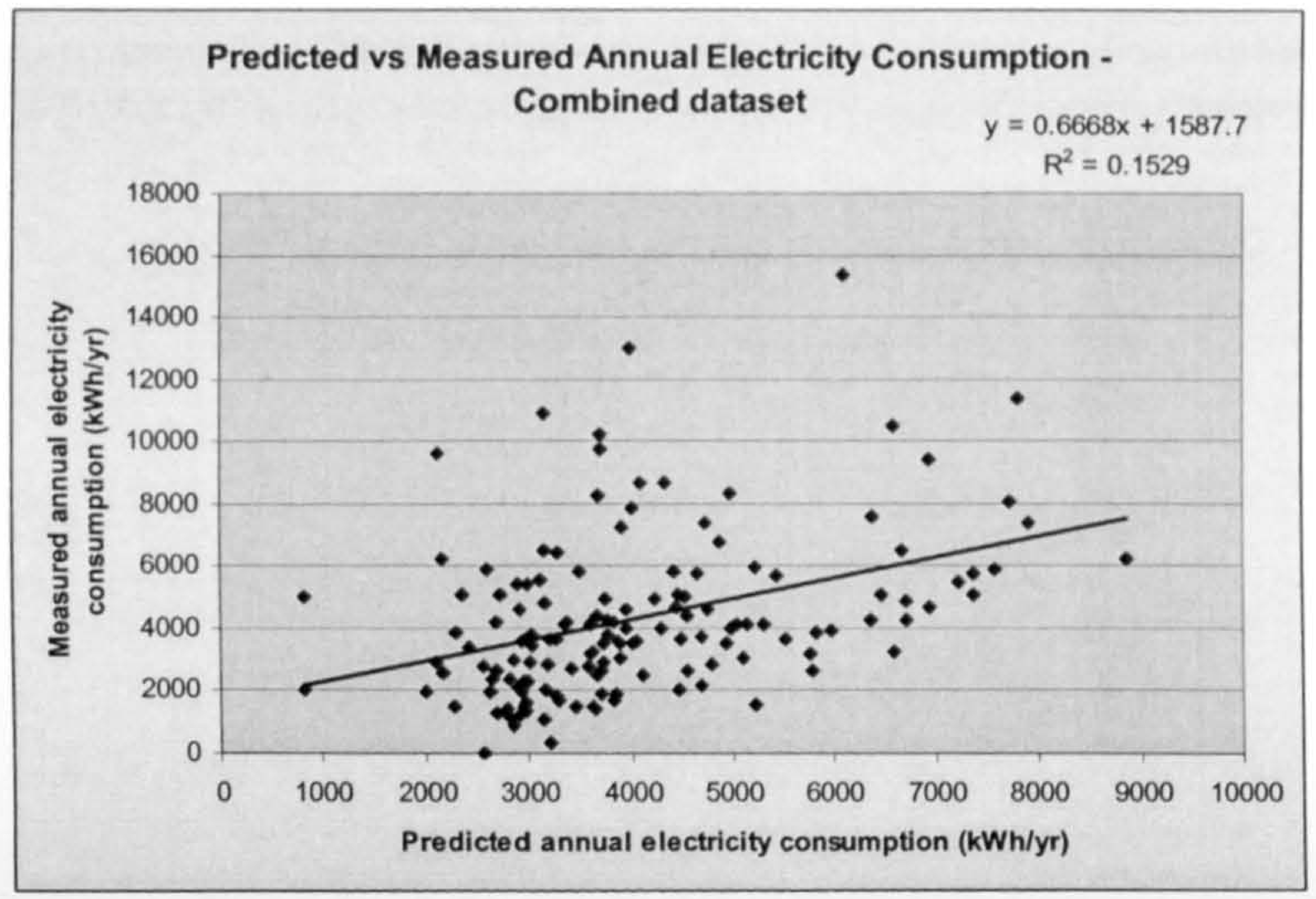


Figure 9.8d. Predicted vs Measured Annual Electricity Use for the combined dataset using ELA + Ek

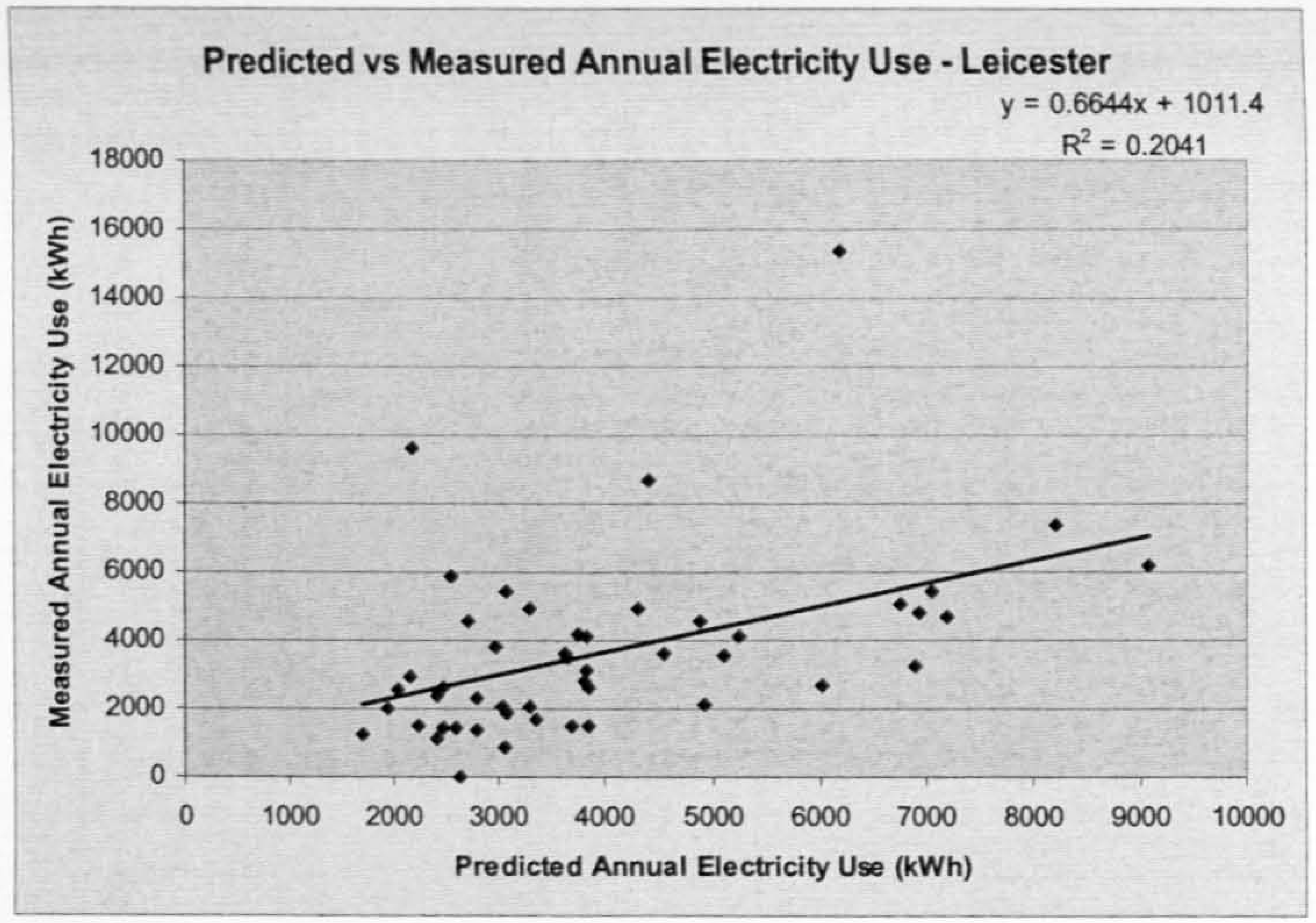


Figure 9.9a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using ELA + AdjEk

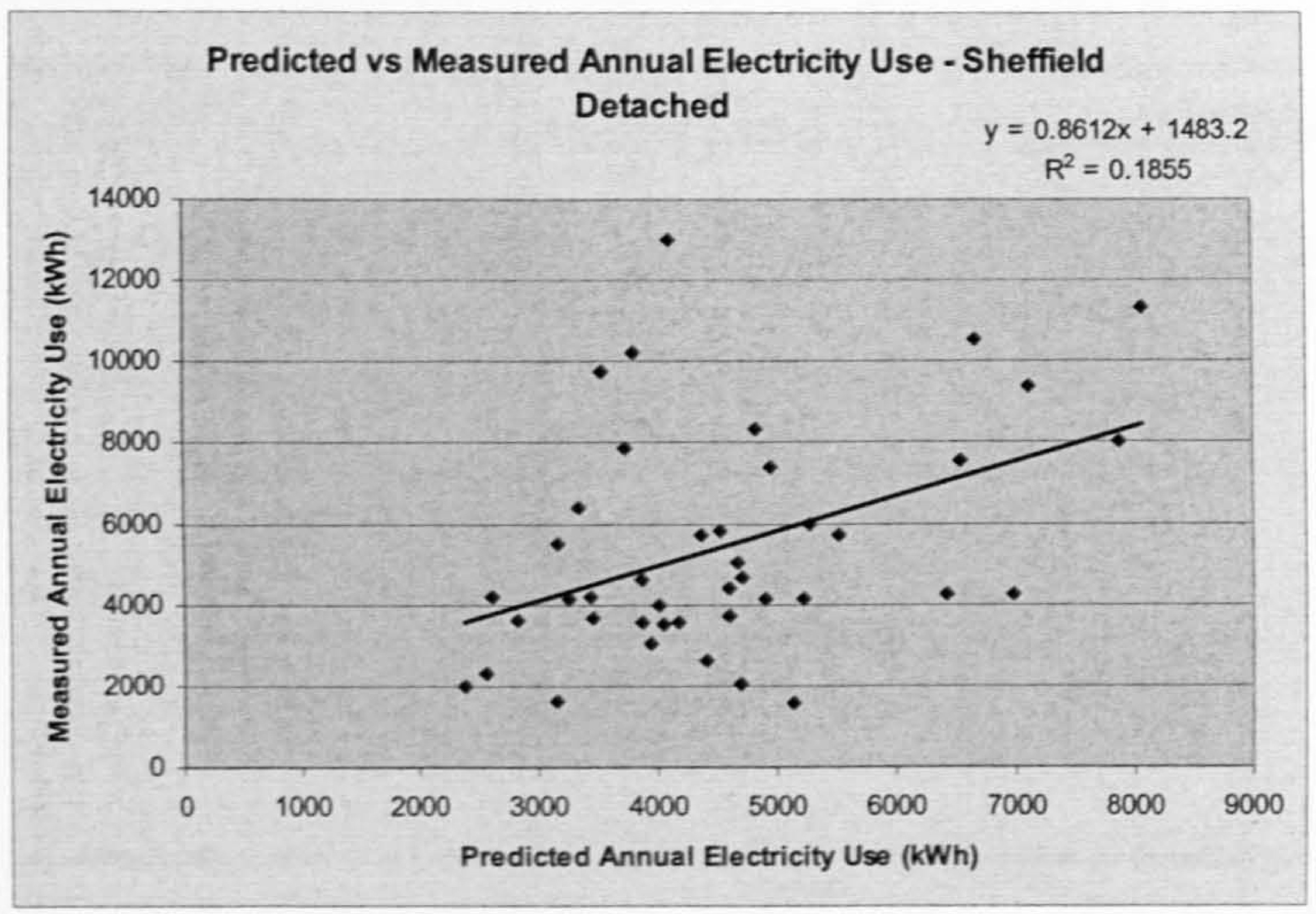


Figure 9.9b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwellings using ELA + AdjEk

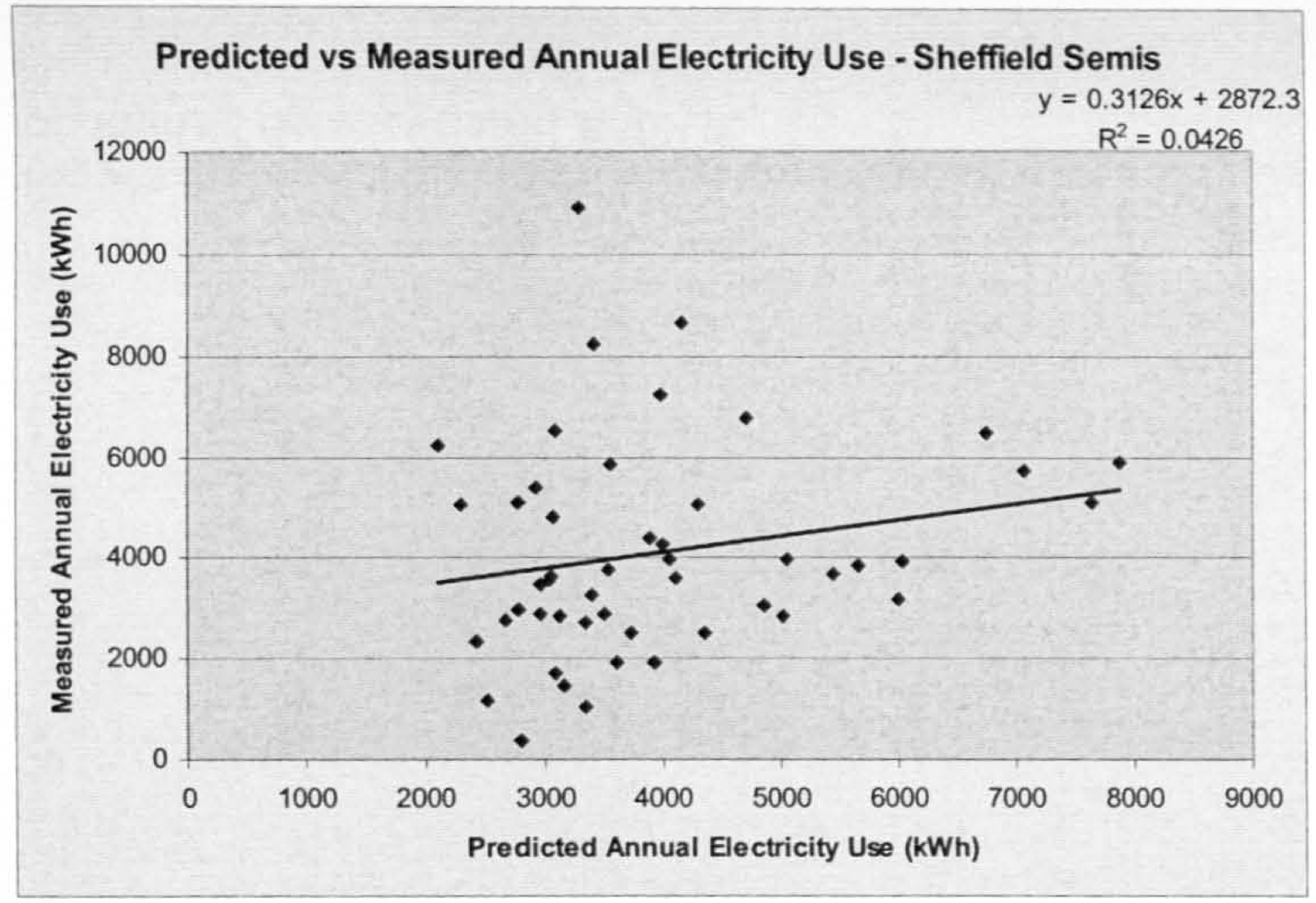


Figure 9.9c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using ELA + AdjEk

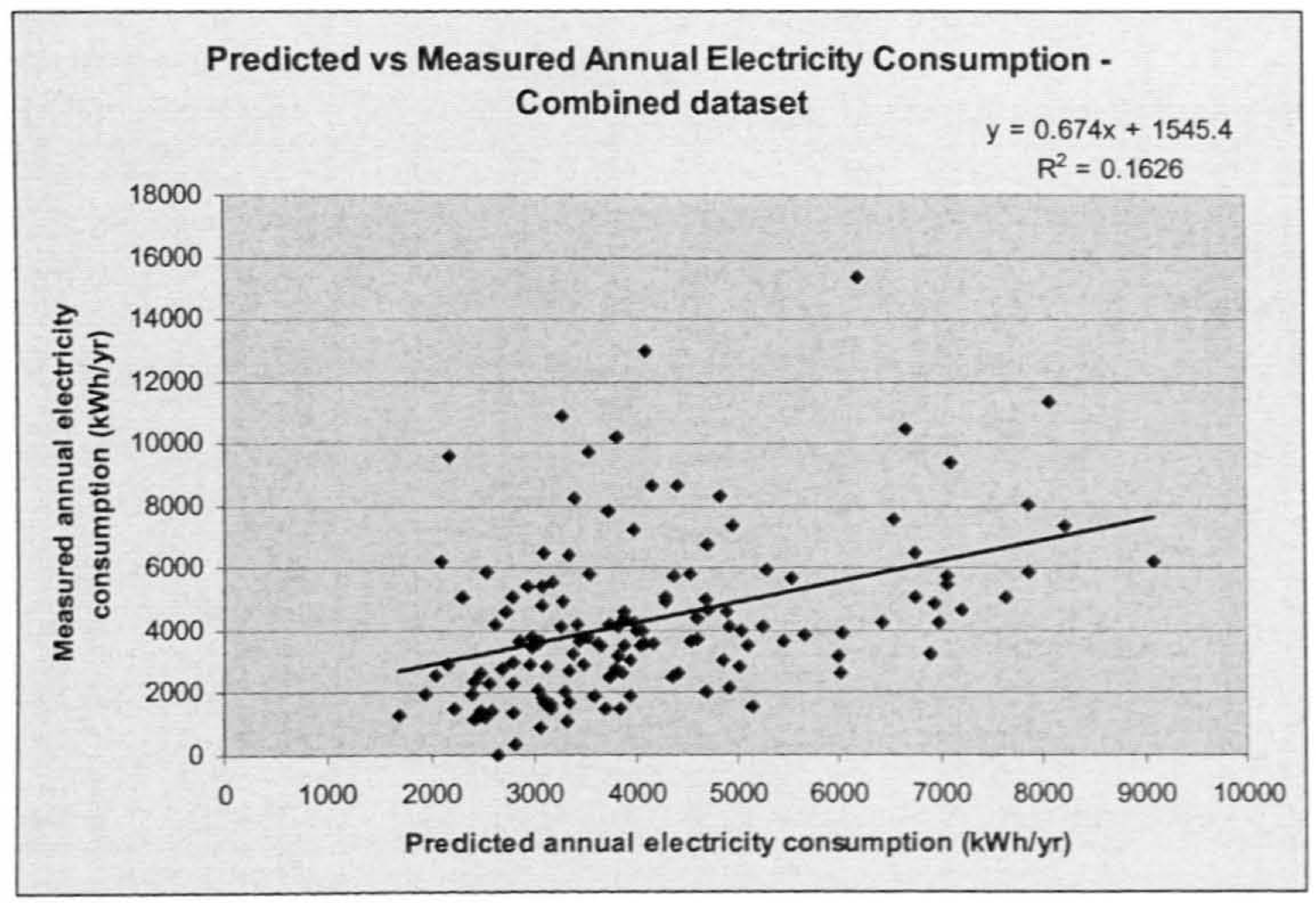


Figure 9.9d. Predicted vs Measured Annual Electricity Use for the combined dataset using ELA + AdjEk

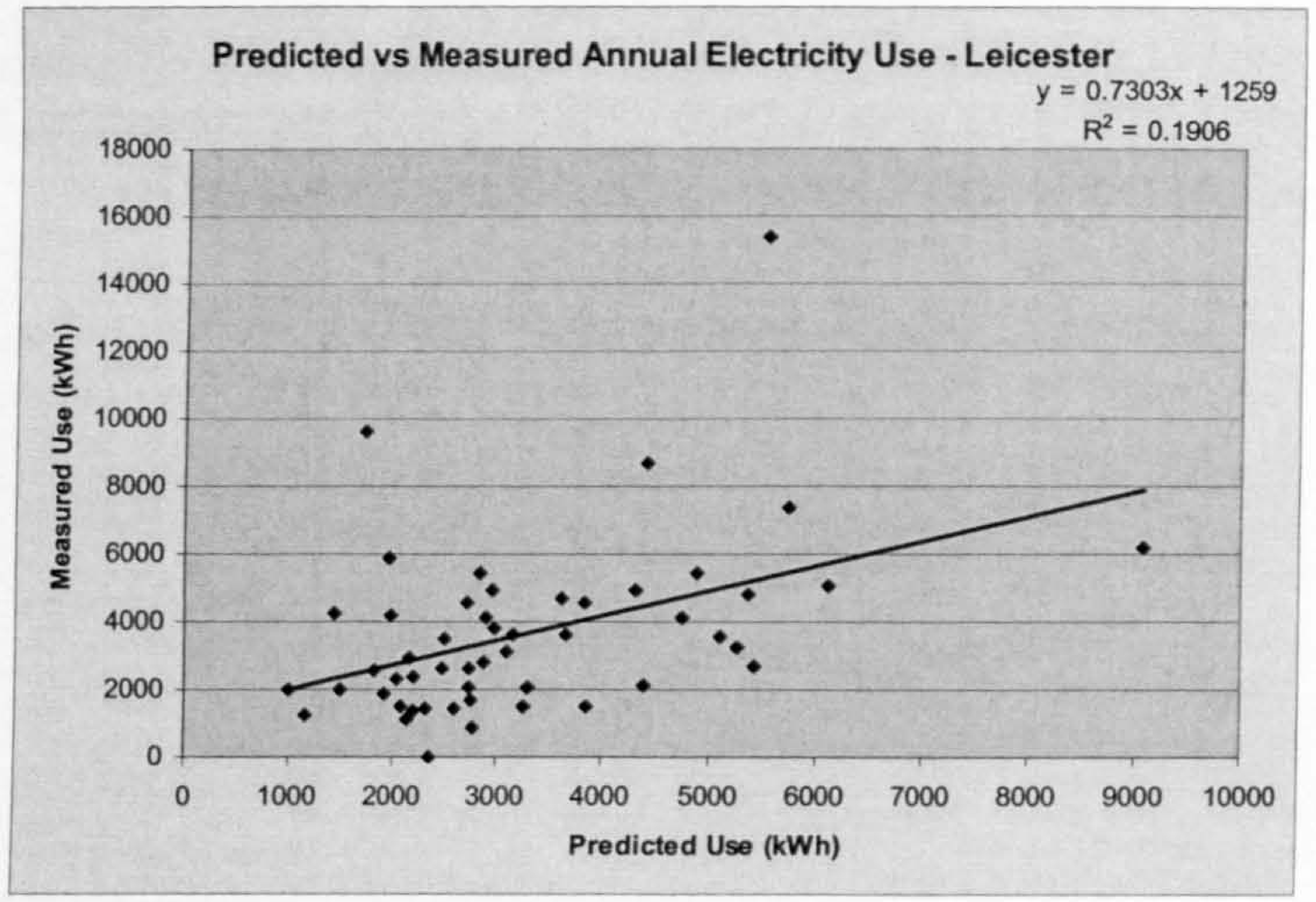


Figure 9.10a. Predicted vs Measured Annual Electricity Use for the Leicester terraces using AdjELA

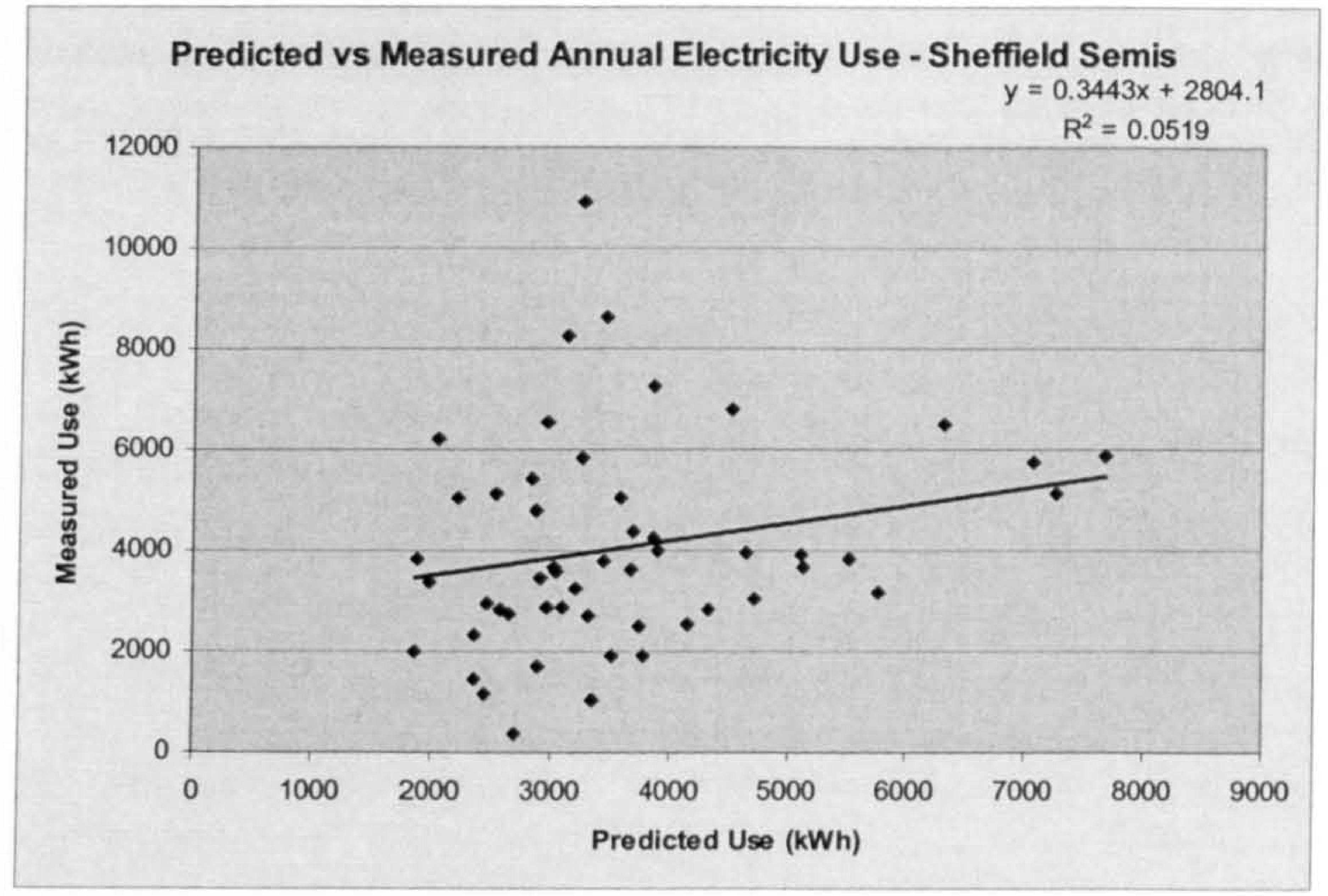


Figure 9.10c. Predicted vs Measured Annual Electricity Use for the Sheffield semis using AdjELA

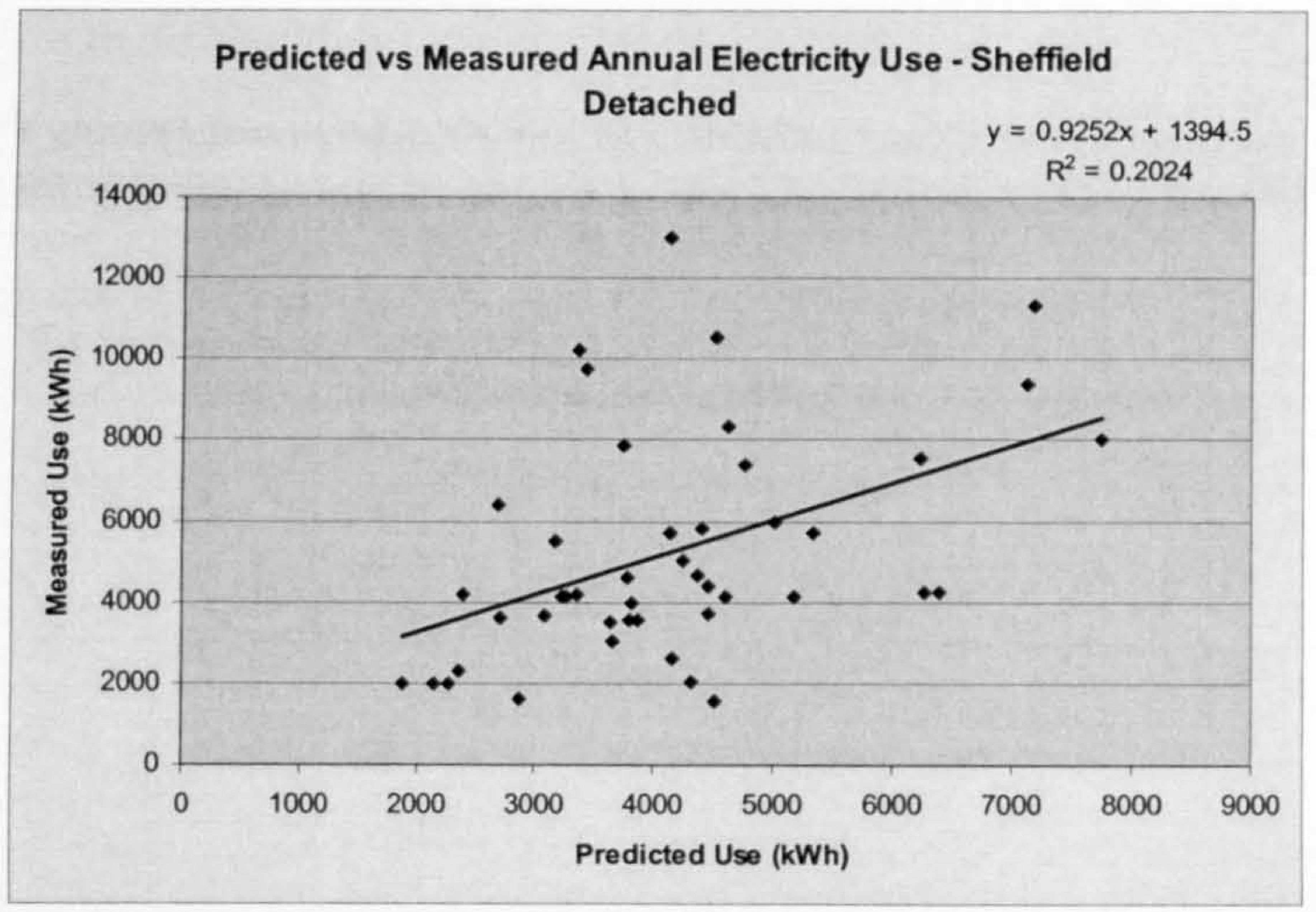


Figure 9.10b. Predicted vs Measured Annual Electricity Use for the Sheffield detached dwellings using AdjELA

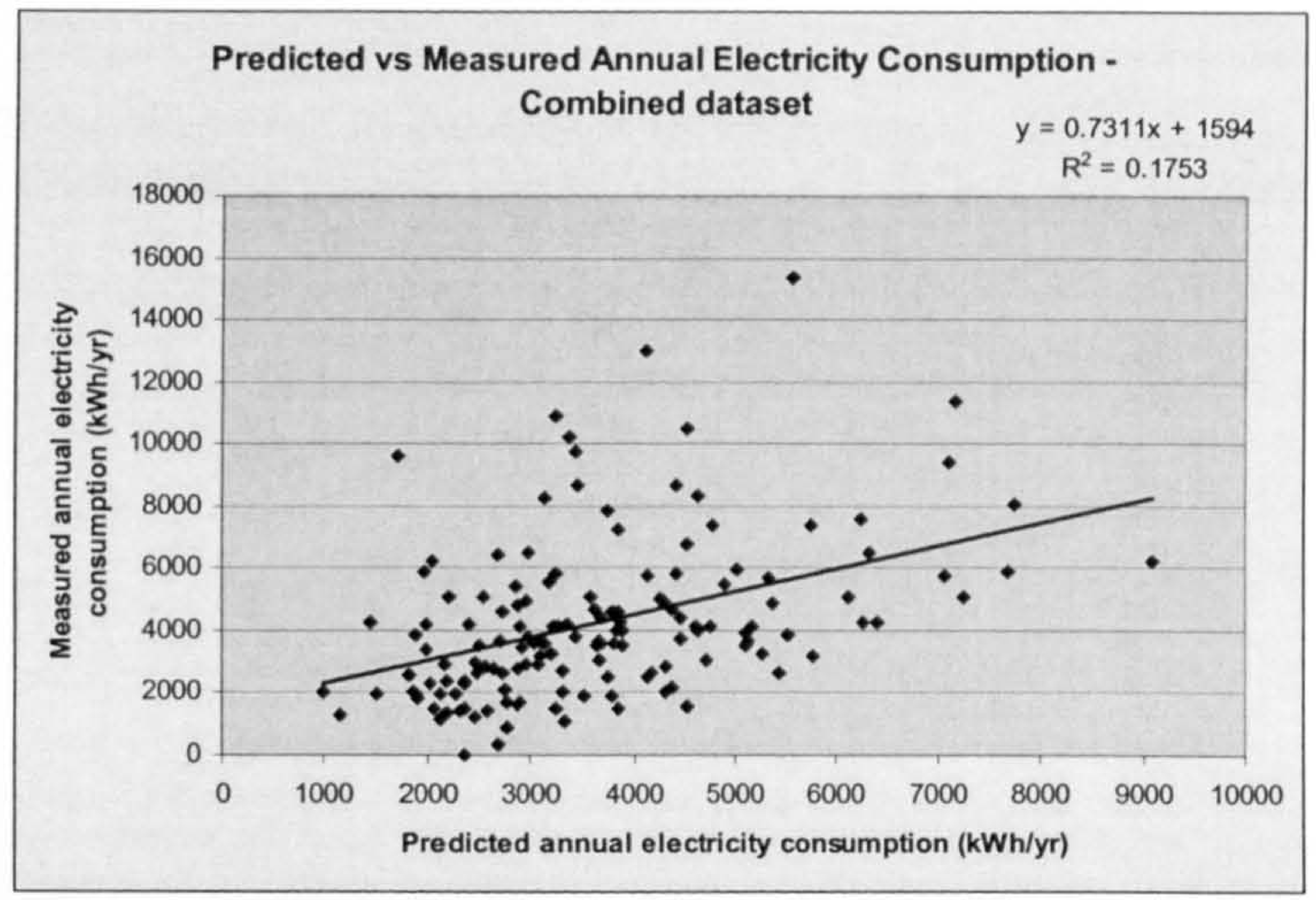


Figure 9.10d. Predicted vs Measured Annual Electricity Use for the combined dataset using AdjELA

A summary of the r^2 values for these correlations is given in Table 9.5. The correlations between predicted and measured electricity consumption are strongest for the Leicester terraces, which conforms with prior expectations that the predictions would be more accurate for the most homogenous sample of built form. The weakest correlations were found for the Sheffield semis, bears out the difficulties of establishing explanatory variables for electricity consumption for this group.

In terms of the modifications to the sub-model for LELs, the simple adjustment using the number of LELs in use divided by the number of rooms ($E_{red}V1$) performed notably better than the weighted adjustment ($E_{red}V2$) for the Leicester terraces, Sheffield detached, and combined samples, and the correlation was only 0.0001 weaker for the semis. However, there is the slight caveat that the BREDEM adjustment could not be applied exactly as the use of LELs in hallways was not questioned. As the use of LELs in domestic lighting sockets becomes the norm rather than the exception researchers developing future models may wish to consider abandoning weighting for LELs.

For cooking it was possible to apply the exact BREDEM adjustment. Here the results are more interesting as when the weighting was calculated using the number of full meals cooked per week reported by respondents ($AdjE_k$) the correlations were stronger than for the basic adjustment (E_k) for all three samples and the combined dataset. This is a useful result as the weighting accounts for this element of occupant behaviour more specifically than the arbitrary (above, below and well below average) BREDEM weighting.

However overall the strongest correlations between predicted and measured consumption were found for the basic E_{LA} equation, with the minor exception of the detached Sheffield dwellings, for which the correlation with $AdjE_{LA}$ was a mere 0.0001 stronger. This is a disappointing result that reflects the complexities of predicting domestic electricity consumption using data at this level of granularity.

Table 9.5. Summary of the r^2 values for the correlations between the predicted and measured annual electricity consumption data

	R^2 values			
Predictor	**Leicester**	**Sheffield Detached**	**Sheffield Semis**	**Combined dataset**
ELA	0.2647	0.2023	0.1012	0.2185
ELA-EredV1	0.2502	0.1639	0.0996	0.2106
ELA-EredV2	0.2326	0.1578	0.0997	0.1906
ELA+Ek	0.2005	0.1770	0.0401	0.1529
ELA+AdjEk	0.2041	0.1855	0.0426	0.1626
AdjELA	0.1906	0.2024	0.0519	0.1753

9.4. Chapter summary

The production and significance of a variable reflecting technology uptake was an unexpected development that came in the very final stages of the analysis, as an attempt to further determine the suggested significance of the number of PCs in use as an explanatory variable. Its main weakness is that as a clustered variable it will require evidence from larger studies to fully ascertain whether or not the generalisations made from the composition of the clusters apply to the wider UK population. However, it is undeniable that the amount of technology in UK homes and the ways in which it is used are changing, and if these changes really are producing an overall increase in domestic energy consumption this will need to be accounted for in both future domestic energy models and policies relating to domestic energy consumption.

The application of the data to the BREDEM sub-model for lights and appliances and the adaptations made to it failed to produce any clear improvements on the predictions of the basic equation. However, the difference between the two sets of correlations that account for LELs casts some doubt on the need for a weighting system, whilst the two sets of correlations that account for cooker use suggest accounting for differences in occupant behaviour may be beneficial to the development of future versions of the model.

Chapter 10. Conclusions, Limitations, and Recommendations for Further Research

10.1. Introduction

The principal achievements of the research described in this thesis are as follows:

- The development and implementation of a methodology for studying differences in domestic energy consumption within and between homogenous groups of dwellings (in this case selected from the fifteen City Form study areas). This is based on a questionnaire developed for use as postal survey, supplemented by data obtained directly from the GIS coverages. This removed the need for intensive on-site surveying which was infeasible within the scope of the research.
- The acquisition of a significant volume of individual annual domestic energy consumption data through a channel previously not accessible to researchers in the UK.
- The discovery of distinct groups of energy consumers within the samples that were shown to be related to differences in a common set of variables within the datasets.
- The discovery of clusters of technology consumers within the combined dataset that were found to be related to differences in electricity consumption and household composition. These clusters were found to be representative of households with high, medium and low uptakes of PC and digibox ownership and broadband access and to relate to socio-demographic differences between respondents.
- The identification of variables with statistically significant correlations with

energy consumption that either confirm previous findings or provide new insights.

- The production of final sets of variables found to be the most statistically significant in determining differences in electricity and gas consumption within the datasets.
- The example application of the data to the BREDEM-8 sub-model for lights and appliances.

The main conclusions from the research are presented in section 10.2. The limitations of the work are discussed in section 10.3, and recommendations for further research based on the results of this study are given in section 10.4.

10.2. Summary of methodology and issues arising

10.2.1. Targeting of homogeneous groups of dwellings

At the outset of the City Form project each partner university identified three study areas within their respective cities composed of between 2,000 and 3,000 dwellings. These were chosen to represent 'city centre', 'city edge' and 'in between' urban environments. Site-surveying using GIS equipped PDAs and photography was used to provide supplementary information on the study areas. Of the fifteen study areas the four used for this study were selected on the basis of having the largest numbers of dwellings of homogeneous built form.

These groups of dwellings were selected using coverages of the study areas in the MapInfo GIS to extract the addresses and calculate the floor areas using the polygons for the outer perimeters of each dwelling. However, the tenements targeted in the Pollockshields area of Glasgow were subsequently identified as being of a built form containing a large circulation space within the building envelope. An attempt was made to calculate approximate floor areas for these dwellings using information from the websites of local estate agents, however this ultimately proved fruitless and the more detailed analyses planned for these dwellings had to be abandoned. Yet despite this oversight the methodology was found to be suitable and effective for use at this scale.

10.2.2. Response rates

The use of postal questionnaires as a means of surveying dwellings for differences in energy consumption is a relatively untested method of conducting research such as this. Therefore a low response rate was assumed from the outset and the results of the pilot project (for which 373 dwellings were targeted) were used to estimate the number of dwellings that would need to be targeted as part of the extended work. This proved useful as the low response rate to the pilot study justified the targeting of all the dwellings of the same built form in each study area (two built forms in the case of the Sheffield study area). The lowest response rate was for the Glasgow tenements, however in this case it appears that many questionnaires were not delivered by the postal service.

In order to produce the three datasets for which the records could be matched with annual energy consumption data and floor area it was necessary to target between approximately 1,500 and 2,100 dwellings in each study area. These datasets are comprised of 52 terraces from the Clarendon Park, Leicester study area and 48 detached and 52 semi-detached dwellings from the Fulwood, Sheffield study area.

10.2.3. Development of the questionnaire

The core content of the questionnaire was based around the NHER Level 1 Site Survey form for houses and bungalows. This was found to be the most suitable survey form for meeting the aims of the study and for adaptation into postal format. The additional questions were incorporated with the aim of further elucidating knowledge of factors influencing differences in domestic energy consumption that have received less or no attention in previously published work. These questions yielded the most interesting results of the study.

The content and level of detail requested from respondents was a trade-off between the data requirements for NHER Level 1, the amount of additional information that respondents could be expected to be willing to supply, and the likely impact on response rates. Based on the evidence of supplementary information being provided with some Home Energy Efficiency Questionnaires used by local authorities and other bodies a set of guidance notes was produced and provided as part of each questionnaire pack. The benefit of this approach was that it enabled the provision of additional information, especially definitions of potentially ambiguous terminology, in a less cluttered format than would have been produced had it been incorporated in the questionnaire itself.

The pilot questionnaire was initially tested on a small number of volunteers and then mailed to 373 dwellings in the Birstall study area. The results from the project were used to inform the revision of the questionnaire and produce the final version used for the extended work. This led to many questions being reduced, extended, and otherwise modified and the overall format of the questionnaire was also substantially revised (see section 3.7). In light of the number of respondents indicating that they did not refer to the guidance notes these were reduced to contain only the most important definitions.

For the extended work an online version of the questionnaire was developed. Although only 6 respondents completed the survey online this version was found to be of great benefit as a means of entering the data from those returned by post as it substantially reduced the time involved.

10.2.4. Data collected

The questionnaire was designed to collect data at a similar level to that of the NHER Level 1 Site Survey form for houses and bungalows, and with the exceptions of dwelling dimensions and a sketch plan contained all the questions from that survey form. The completion rates for these questions were high and fit for purpose and the resulting dataset is evidence that it is possible to use a postal survey to obtain data at a higher level of detail than simply NHER Level 0.

Some of the additional questions included in the final version of the questionnaire were less well completed, in particular those requesting appliance energy efficiency ratings. However, the appliance ownership questions were well completed and produced some of the most interesting results of the study.

Overall the questionnaire was found to be an effective means of obtaining the information being sought and the work has already been used to inform the development of a similar questionnaire being used by the Carbon Reduction in Buildings (CaRB) project, in which the IESD is a partner.

10.2.5. Obtaining individual annual energy consumption data

Several methods were employed to gain access to individual annual energy consumption data for the dwellings targeted in each study area. Respondents to the pilot project were provided with a mandate form to give permission for the release of their energy consumption data from the utility companies. This also gave them the option to provide copies of their energy bills and/or contact details to arrange a site visit for a meter reading. Negotiations with two major utility companies, E-on and Centrica, eventually proved fruitless despite initial enthusiasm for participating in the work from representatives of E-on. A major problem with building relationships with utility companies is the turnover of staff during the periods of time involved in conducting research projects such as this, and also the lack of a financial pay-back for their cooperation. This should be born in mind by other researchers considering making similar approaches.

During the development of the final version of the questionnaire it was discovered that the DTI had collected individual annual electricity and gas consumption data for 2004, and negotiations with the department led to an agreement to release this data provided a legally acceptable format for the mandate form could be agreed. This form is provided in Appendix 5, along with the questionnaire itself and the cover letter outlining the terms for the storage and use of this data. Gaining access to this data was essential for the success of the study and consumed a significant amount of the time available, however once this breakthrough was made the mandates were processed by the DTI and the data was obtained within a week. This study represents the first, and so far only, instance that this data has been released.

10.3. Conclusions

10.3.1. Clusters of energy consumers

- Three clusters of energy consumers were discovered in the data, representing high, medium and low energy consumers. These were not found to be representative of the three built forms surveyed (terraces, semis and detached dwellings) however, they were found to be related to differences in total floor area (TFA) total occupancy, dwelling age, numbers of rooms, numbers of bedrooms, and whether or not respondents reported regularly working from home. There was also weaker evidence of correlations with other variables and these were explored further using multiple regression analysis.
- Within the individual samples two clusters of higher and lower energy consumers were discovered. These clusters were also found to correlate with the variables found to explain the differences in energy consumption for the combined dataset.
- Two clusters of higher and lower energy consumers that were distinct by both gas and electricity consumption when the combined dataset was re-clustered using these variables. As before these clusters were not found to relate to differences in built form, suggesting that other factors were obfuscating the influence of built form at this level of analysis.

10.3.2. Simple correlations between energy consumption and TFA

- The data for the study areas was categorised based on the variables from the questionnaire and simple linear regression backed with visual inspection of the scatter plots was used to identify those categories in which the strongest correlations were found between gas or electricity consumption and TFA. The results of these analyses produced the table of r^2 values given in Appendix 7. These correlations were used in conjunction with the evidence from clustering to inform the selection of variables for the further analyses using multiple regression.
- These analyses showed a strong relationship between gas consumption and TFA for those households with the greatest control over their levels of thermal comfort, i.e. those living in dwellings with TRVs, digital heating controls and thermostats. It was not possible to elucidate further on this relationship, however it may be a promising area for further research on larger datasets.

10.3.3. Confirmatory analyses of the data

- The evidence for the strength and statistical significance of the variables identified from the exploratory clustering and simple linear regressions was confirmed by using multiple regression on the datasets. This produced more accurate and reliable statistical measures of their significance, in particular for influences of differing numbers of bedrooms and that of homeworking.
- In addition to confirming the statistical significance of the relationships between consumption and the variables described thus far these analyses enabled the identification of other variables significant in explaining either

only electricity or gas consumption. Some of these, for example washing machine use, were found to be significant only for individual samples, however others, for example the number of portable electric heaters in use, were found to be significant for more than one sample and for the combined dataset.

- These analyses led to the production of the tables given in section 7.7, which show the strength and significance of the sets of variables found to be most significant in explaining differences in gas and electricity consumption for the dwellings within the individual samples and the combined dataset.
- It is probable that larger and more conclusive sets of explanatory variables for energy consumption could be found if this methodology is applied to larger datasets, however the limit of a condition index of 30 indicating strong statistical evidence of collinearity limited the number of variables in each of these tables.

10.3.4. Significance of the number of bedrooms and homeworking as explanatory variables for energy consumption

- The most statistically significant correlations between any variable and both gas and electricity consumption were found for the number of bedrooms. The correlations with this variable and energy consumption were found to be consistently strong and statistically significant at the highest level. Furthermore, there was no clear and statistically significant evidence of collinearity between this and any other variable analysed. This is a variable not commonly questioned by existing energy surveys and as such deserves attention when future studies are being developed. The strength and statistical significance found for the correlations between energy consumption and the number of bedrooms may be indicative of changes in the way households are heating and using their dwellings. This may reflect smaller households opting to heat specific rooms rather than entire dwellings and the increasing use of appliances such as TVs and PCs. Further evidence for possible changes in heating regimes is suggested by the correlations found between electricity consumption and the number of portable electric heaters in use. Bedrooms were found to be the second most common room in which secondary heating was in use, however it is not possible to conclude that the two are directly related as respondents were not asked to specify in which room each form of secondary heating was used.

- Another strong and statistically significant set of correlations was found between energy consumption and homeworking. As is discussed in section 7.6 there is a growing trend in the UK towards more employees regularly working from home. This explains why this factor has received scant attention in previous energy surveys but the evidence from this research suggests that future energy studies should question and account for the influence of homeworking on domestic energy consumption.
- These two results suggest that the study has identified a possible underlying relationship between changes in occupancy and energy use regimes that supports the results of other studies on changes in these trends amongst the wider UK population. However, further research is necessary to provide conclusive evidence of these changes and their likely impact on UK domestic energy demand.

10.3.5. Technology uptake and domestic electricity consumption

- The exploratory analyses of the data identified TV, PC and digibox ownership as weaker influences on domestic energy consumption. Two step clustering was employed to determine if clusters of technology consumers existed within the data and three clusters were found reflecting differences in PC and digibox ownership and broadband access. Strong and statistically significant relationships were found when these clusters were crosstabulated with the banded electricity consumption data, and also when the cluster numbers were used in multiple regression analysis. This new variable was not used in the development of the tables of explanatory variables produced from the multiple regressions as it is not possible to ascertain whether similar clusters exist in the wider UK population. However, technology consumption by UK households is changing (see section 2.2.7) and this can be expected to have an increasing impact on domestic electricity consumption. Therefore there is a clear need to study these changes and their influence on electricity consumption in order to predict future changes in demand.

10.3.6. Application of the data to the BREDEM-8 sub-model for lights and appliances

- When the relevant data from the questionnaire was used with the BREDEM-8 sub-model for lights and appliances weak correlations were found between the predicted and measured annual electricity consumption. Modification of these predictions using the adjustments for low energy lighting and cooker types failed to improve the strength of the correlations. However, they do suggest that it is possible to produce approximations of the data requirements for BREDEM-8 without the need for resource-intensive site-surveys. In terms of the level of detail that can be gained from different approaches to studying domestic energy consumption there is no substitute for on-site surveying and monitoring, however this is rarely feasible at a scale such as this. This study has demonstrated the potential value of using reported data with individual annual consumption data and it is hoped that the lessons learnt will be useful in informing the work of other researchers engaged in similar studies in the future.

The work presented in this thesis will be summarised in a chapter of a forthcoming book to be published as an output of the City Form project.

10.4. Limitations

As with any study the results and conclusions presented in this thesis are framed by their limitations. The following is a list of those that apply to this study and how they affect the interpretation of the research.

10.4.1. Sampling strategy

The low response rate to the pilot study was accounted for by significantly increasing the number of dwellings in each study area targeted for the extended work. However, the greatest value of the data was the number of records that could be matched with floor area and consumption data. The number of questionnaires returned with completed mandate forms as permission for the release of consumption data was a small fraction of the total number of questionnaires returned. In hindsight it may have been better to ask respondents only to complete the questionnaire if they were willing to complete the mandate form as an acceptable trade-off between the volume and usefulness of the data collected. Floor area could not be accurately calculated for the Glasgow tenements and this removed this group from all but descriptive analyses. Although this factor was overlooked at the time the study was rolled out the evidence for the internal layout of the buildings only came to light later when aerial photos of the area were made available online. However, this was largely irrelevant due to the alleged returning of many questionnaire packs as sent to invalid addresses by the Glasgow postal service that significantly reduced the number of dwellings being surveyed. Although at the time of writing this has not been established beyond doubt the evidence from the number of questionnaire packs returned compared to the number of reminder letters returned supports a similar experience by the City Form group studying transport.

10.4.2. Sample size

The size of the datasets is the key limitation on all the analyses conducted as part of this study. Smaller samples limit the range of appropriate analytical techniques and the interpretation of all but the most significant results from the study. However, as discussed in the literature review, section 2.1, sample size is invariably a trade-off with other factors when designing studies of domestic energy consumption. The benefit of studies conducted at this mesoscopic scale is that, as this study has proven, they are capable of elucidating factors influencing domestic energy consumption within groups of dwellings too large for on-site surveying to be feasible. Even so, further work is still necessary to validate the conclusions stated here.

10.4.3. Self-selection of respondents

The analyses of the socio-demographic data for the respondents to this study shows that the vast majority are educated and either retired or in professions that put them in the 'AB' category of approximated social grade. Some of this bias is likely to be related to the areas selected for study, however this is more likely to be due to the attitudes of these groups to taking part in surveys. Postal surveys such as this will always be open to a degree of bias from self-selection, a factor which may be more pronounced for this study due to the relatively technical nature of the questionnaire. However, the benefit of gaining new data by deliberate targeting of less affluent and educated households is likely to come at the cost of a lower response rate.

10.4.4. Use of annual consumption data

Gaining permission for the release of annual consumption data from the DTI is the big success story to have emerged from this study, and at the time of writing this study still represents the only release of this data. Therefore there are no comparable UK studies against which to assess the results from this research, and the Australian study from which this work draws much inspiration is notably different in terms of the scope of factors being analysed. Of key concern is the accuracy of this data, however there was absolutely no evidence to be suspicious of the assurances gained from the DTI regarding this.

Most of the analyses conform with expectations and thus confirm the validity of the data, with a minor caveat regarding the unusual variation in the consumption data found for the Sheffield semis.

10.5. Recommendations for Further Research

These results have raised many new questions that deserve further investigation. Additional evidence for many of the relationships found or suggested could be provided through the addition of a small number of simple questions to future energy studies. Other suggestions of relationships would require more detailed and specific studies to accept or reject them. The following is a summary of those suggested by the results as being most promising for further research.

- Number of bedrooms. This data is now being collected as part of the HEED project. Simple analysis using the much larger datasets being collected for this project could confirm, or otherwise, the high level of statistical significance found for this variable as a determinant of differences in dwelling energy consumption.
- Homeworking. As for the number of bedrooms the inclusion in future energy studies of a simple question of the form used for this study could further establish the significance of this variable. However, there shoul be even more to learn from studies that include more detailed assessments of occupancy regimes.
- Impact of technology uptake. The conclusions reached regarding the influence of technology uptake on domestic energy consumption are a

little tentative, however there is a strong suggestion that changes in technology consumption are influencing energy consumption. The three variables clustered to produce a measure of this impact may not be the only useful indicators here, and there is a clear scope for the extension of this research. The main problem with developing such studies is the rate of technology change. Even planning for a study to commence after a major technological shift, e.g. after the switching off of analogue transmitters, may hit the problem of another major shift occurring soon after.

- Clusters of energy consumers. The clustering of the data from the questionnaires indicated two relatively distinct groups in each sample that could be generalised as smaller, lower occupancy, lower consuming households and larger, higher occupancy, higher consuming households. The small sample sizes make it difficult to conclude how representative these groups are of differences in the UK population by energy consumption. The full picture may be more complex, with more clusters representing generalisations of other groups or sub-groups within these clusters. However, if future studies can confirm the existence of distinct groups of energy consumers it would doubtless be of huge benefit to informing energy policy.

- Space heating controls. The study found a strong relationship between gas consumption and TFA for dwellings fitted with TRVs, digital heating system controls and thermostats. This may be indicative of these households using these controls to optimise their thermal comfort levels, and perhaps also their energy regimes with respect to space heating.

- Use of electric heaters. If the way occupants heat their dwellings is indeed changing towards one of heating specific rooms rather than whole dwellings the use of electric heaters may provide a useful indicator of the strength of this trend. As few dwellings have gas fittings outside of the main living area, kitchen and bathrooms electric heaters are the easiest option for providing heat without expensive modifications. Portable heaters also provide greater flexibility and can easily be moved around or between rooms. Therefore if occupants' heating regimes are changing in this way this could be manifesting itself in an increased use of electric heaters.

- Use of mechanical ventilation. The results show very few respondents reporting the use of mechanical ventilation systems, however with average UK summer temperatures continuing to rise it seems inevitable that this will eventually lead to significant numbers of mechanical ventilation or air-conditioning systems in UK homes. Gaining evidence from market research on these systems may help to indicate the earliest point at which work in this area may bear fruit in terms of assessing the impact on domestic energy consumption.
- Dishwashers. The evidence for the impact of dishwashers on domestic energy consumption remains conflicting and contested. It would no doubt benefit energy policymakers to recommend consumers either purchase or avoid purchasing these appliances if they are seeking to reduce their energy consumption. However, conclusively answering this question clearly requires more detailed investigation of how they are used, not simply how frequently, and how much of the electricity used by them for heating water offsets the energy used for water heating by main heating systems.

Glossary of Abbreviations

ASG: Approximated Social Grade

BREDEM: Building Research Establishment Domestic Energy Model

CaRB: Carbon Reduction in Buildings project

CFL: Compact Fluorescent Lamp

DEFRA: Department for the Environment, Food and Rural Affairs (UK)

DETR: Department for the Environment, Transport and the Regions (UK)

DHW: Domestic Hot Water

DTI: Department for Trade and Industry (UK)

EEP: Energy and Environment Prediction model

EMERALD: Estimating Municipal Energy for Residences using Arbitrary Levels of Data

EPSRC: Engineering and Physical Sciences Research Council

EU: European Union

GIS: Geographical Information Systems

HDTV: High Definition TV

HECA: Home Energy Conservation Act

HEED: Homes Energy Efficiency Database

HEEQ: Household/Home Energy Efficiency Questionnaire

LCD: Liquid Crystal Display

LELs: Low Energy Lightbulbs

mtCO2e: million tonnes carbon dioxide equivalent

MPAN: Meter Point Administration Number

MPRN: Meter Point Reference Number

MTP: Market Transformation Programme

NEF: National Energy Foundation

ODPM: Office of the Deputy Prime Minister (UK)

ONS: Office for National Statistics (UK)

OS: Ordnance Survey

PDA: Personal Digital Assistant

PDP: Plasma Display Panel

POST: Parliamentary Office of Science and Technology

ppb: Persons Per Bedroom

SAP: Standard Assessment Procedure

SUFC: Sustainable Urban Form Consortium (also known as CityForm)

VCR: Video Cassette Recorder

Glossary of Statistical Terms

Note: some of the terms and tests listed here are used or interpreted differently depending on the analysis in question. The definitions and interpretations listed here are only those that apply to the analyses described in this thesis.

Clarification regarding 'continuous' and 'categorical' variables: for two-step clustering SPSS classifies variables as either 'continuous' or 'categorical'. In reality these are inexact classifications of many of the variables analysed as part of this study, however the SPSS convention is maintained for ease of reference with the software and outputs from the analyses. The use of two-step clustering and the interpretation of the outputs from this analytical technique are covered in Chapter 5.

Adjusted r^2 value: a modification of the r^2 value that adjusts for the number of explanatory terms in a regression analysis or model. The value only increases if a new variable improves the correlation more than would be expected by chance.

ANOVA significance value (or 'p value'): This is the conditional probability that a relationship as strong as the one observed in the data was present. A value below 0.05 is considered highly significant.

Chi-square test: a measure of the statistical significance of the evidence for independence between two or more groups in a dataset. Used in this thesis as the measure of the importance of a categorical variable in determining the clusters produced from two step cluster analysis.

Condition Index: this is the measure of collinearity used in this thesis and is the ratio of the square root of the largest eigenvalue to the corresponding eigenvalue associated with each variable in a multiple regression. For the datasets from this study the condition index is a better measure of collinearity due to the numbers of records and variables, but also due to the fact that many variables are either bivariate (0 or 1) or have only a small number of possible outcomes. Therefore evidence of collinearity from the eigenvalue may be due to simple chance rather than causality. A condition index above 15 is suggestive of collinearity, whilst a value above 30 indicates a serious problem with collinearity.

Eigenvalue: a measure of collinearity that indicates the number of distinct dimensions amongst the independent variables in a multiple regression. Values close to 0 indicate a problem with collinearity.

F statistic (change): This is a measure of how well a new variable improves each correlation. A value below 0.05 indicates high statistical significance. Given the limitations of the datasets this statistic was interpreted more loosely later on when larger numbers of variables were being analysed together, with a value of around 0.1 deemed justifiable.

Pearson correlation coefficient: the basic measure of the strength of a linear relationship between two variables. Values are between -1 and 1 and indicate the strength and direction of the correlation.

r^2 value: the basic measure of the strength of a correlation between two or more variables, also known as the coefficient of determination. Values above 0.5 are indicative of a strong relationship between the variables, and values between 0.25 and 0.5 are indicative of a weak relationship.

Spearman correlation: a non-parametric version of the Pearson correlation coefficient suitable for use with data that is ordinal or approximately ordinal. Values are between -1 and 1 and indicate the strength and direction of the correlation.

Student's t-test: a measure of the statistical significance of the evidence for independence between two or more groups in a dataset. Used in this thesis as the measure of the importance of a continuous variable in determining the clusters produced from two step cluster analysis.

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Appendices

Appendix 1: Comparison of Data Requirements and Sources

Comparison of Data Requirements and Sources

Data category	Information required - EMERALD	Minimum data sources and default-derivation - EMERALD	RDSAP data requirements (brackets indicate options on survey form)	Data source (if not from on-site survey)	NHER Level 0	NHER Level 1	Data source (if not from on-site survey)	Energy Questionnaire data - X indicates data meets all/any EMERALD/RDSAP/NHER Level 1 requirements listed	Data source (if not from EQ)
Site definition	Degree day region	User							
	Height above sea level (m)	User/Map							
	Number of sides sheltered from wind and mean site wind speed	Map/BRED EM-8 table							
	Level of overshading	Assumed average							
Geometry of dwelling	Number of storeys	User knowledge/ Map	Number of storeys		Number of storeys	Number of storeys		X	
			Number of rooms (excluding hall, stairs and landing)		Number of rooms (excluding hall, stairs and landing)	Number of rooms (excluding hall, stairs and landing)		X	
								Number of bedrooms	

	Definition of zones 1 and 2, noting whether zone 1 is all of a storey and whether the stairs provide a direct link between zones and 2	Assumption							
	Total floor area for each zone, volume for each zone	Map/Standard dwelling based on built form				Dwelling dimensions and sketch plan		Total floor area	External perimeter derived from GIS coverage, multiplied by no of floors (from EQ)
			Semi-exposed wall lengths - 1st and 2nd conservatory / garage wall(s) (m)					Could be derived from detachment (mid-terrace with passageway, etc)	
Built form	Built form (including detachment)	Map / Local authority records / Drive-past survey, etc	Built form (house, bungalow, flat or maisonette)		Built form (houses and bungalows only, but includes back-back dwellings)	Built form (houses and bungalows only, but includes back-back dwellings)		Built form - does not include back-backs but does include tenements - otherwise as for RDSAP	Or from walk-by surveys, local knowledge or GIS

			Detachment (e.g., semi, mid-terrace with passageway)					X	
	Age	Local authority records / Local knowledge / Drive-past survey, etc	Main property age		Age	Age		X	Or from walk-by surveys, local knowledge or GIS
						Basement/ Cellar		X	
Extensions			Extension age			Extension age		X	
								Extension type (single/double storey, loft/garage conversion, other)	
			Room in roof age					X	
			Extension construction insulation (external, filled cavity, internal, as built, unknown)			Extension constructio n insulation (external, filled cavity, internal, as built, unknown)		X	

			Extension roof construction (pitched, flat, other dwelling above)			Extension roof constructio n (pitched, flat)		X	
			Extension roof insulation at (rafters, joists, no access)						
			Extension roof insulation at joist level (thickness in mm or don't know)			Extension roof insulation thickness (in mm)		Extension roof insulation thickness (in mm)	
Flats and maisonettes only			Heat loss corridor (none, heated, unheated, plus length of sheltered wall (in m) if unheated)						
			Floor number					X	
			Number of floors in block					X	
			Heat loss floor present (Y/N)						
Building fabric	Area of roof, external walls, for each zone	Inferred from map-derived data / Standard dwelling							

	Type of construction (e.g. timber frame / cavity wall)	Based on age	Type of construction and/or U-value (noting wall type)			Type of constructio n (e.g. timber frame / cavity wall)		X	
	Insulation - U-values of roof, external walls, for each zone	Standard dwelling / UK building regs	As above					X	
	Heat loss floor area for each zone, floor perimeter	Standard dwelling / UK building regs	Internal and external perimeter / dimensions - floor area, room height and heat loss perimeter for each floor						
	Type and amount of insulation	UK building regs			Type and amount of insulation	Type and amount of insulation		X	
			Shelter factors related to built form (unheated conservatory, integral garage, attached garage)					Data for conservatories but not garages	
			Garage type (single, double, other)						

			Fascia cladding present (Y/N)			Additional cladding (internal or external)		X	
			Additional walls - construction type, fascia cladding, additional construction insulation, wall area (m2), part of main dwelling or extension						
			Roof construction (pitched, flat, other dwelling above)					X	
			Main roof insulation at (rafters, joists, no access)					Thickness of roof insulation, but not specified at rafters/joist level	
			Main roof insulation at joist level (thickness in mm or don't know)						

Glazing	Window areas, type of frame, type of glazing, level of leakiness (e.g., draught stripped, loose fitting), orientation, zone	Standard dwellings / Map	Area of glazing (normal, more than typical, less than typical)		Type of glazing and frame type (percentages)	Type of glazing and frame type (percentages)		Main type of glazing and frames	
			Proportion double glazed (%)						
			Double glazing installed (pre-2002, during/post 2002, don't know)						
Conservatories	Conservatory floor area					Conservatory floor area			
	Conservatory glazing (double glazed Y/N)					Glazing type		X	
	Glazed perimeter								
	Room height (storeys)								
						Frame type		X	
Ventilation system	Pressure test result	Assumed none							

	Number and type of fans and vents	UK building regs / Assumption							
	Type	EHCS							
	Fuel	EHCS							
	Number of pumps and fans	Assumption							
						Mechanical ventilation installed (Y/N)		X	
Main heating system			Main heating system type (manufacturer, model, boiler ID, SEDBUK Ref no.)		Main heating system type and fuel	Main heating system type (manufacturer, model, and ID number)		X	
						Extent of main heating (most/all rooms, living / dining rooms only, bedrooms only)		X	
			OR type (underfloor, radiators, etc)					X	

	Controls fitted (e.g. room thermostat)	Assumption	Heating controls - dependent on system type (programmer, thermostat, TRVs, bypass, flowswitch, load compensator, manual/automatic charge controls, zoned heating, district heating, etc)					TRVs, thermostat and setting, zoned heating and number of zones. Storage heaters - old/modern, manual/automatic charge controls, fan- assisted. Gas fires - old/modern, back boilers, condensing. Solid fuel room heaters - open/closed, back boiler. Underfloor heating by fuel type (including gas ducted warm air)	
	Level of independent control in zone 2 (e.g. TRVs)	EHCS						X - but not specified as zone 2	
	Type	EHCS						X	
	Fuel	EHCS						X	
			Efficiency	From look-up tables					

Secondary heating	Secondary heating, type of appliance and fuel	EHCS	Type of appliance, fuel, controls, plus back boilers, open to chimney, throat restrictors, flue type, panel, convector or radiant heaters (where appropriate) for gas, solid fuel, and electric room heaters			Secondary heating, type of appliance and fuel		Type of appliance, fuel and where used (livinng/dining room, bedroom, kitchen, bathroom, other).	
			Use of portable electric heaters					Use and number used regularly in cold weather.	
								No. of fixed electric heaters	

Hot water heating	Type of hot water heater (e.g. from boiler, electric immersion)	EHCS	Type of hot water heater, part of main/secondary heating system or independent. Also includes heat exchangers built into gas warm air systems and differentiates between single/dual immersion		Type of hot water heater (e.g. from boiler, electric immersion)	Type of hot water heater (e.g. from boiler, electric immersion)		X	
	Volume of hot water tank	UK building regs	Volume of hot water tank (no cylinder, no access, normal, medium or large)			Volume of hot water tank (no cylinder, no access, small, medium or large)		Volume of hot water tank (no cylinder, no access, small, medium or large)	
	Thickness and type of insulation	UK building regs	Insulation type (none, jacket, spray foam) and thickness in mm.			Insulation type (none, jacket, spray foam)		Insulation type (none, jacket, spray foam)	
	Whether primary pipework is insulated	UK building regs							
	Whether there is a cylinder thermostat	UK building regs	Whether there is a cylinder thermostat						

	Location of tank (zone 1 or 2)	Assumed 2							
	Area of solar panel (if fitted)	Assumed none	Presence of solar water heating (Y/N)					Presence of solar thermal, PVs, micro-wind, micro-CHP, and if the device is working.	
								No. of showers and baths per week	
								Boiler last serviced (within the last year/over a year ago)	
								Boiler age (more/less than 10 years old)	
Mechanical ventilation	Efficiency of heat recovery (if present)	Assumed none						Use of mechanical ventilation (Y/N)	
Cooking	Cooking system and fuel used (e.g. electric cooker, kitchen range)	EHCS				Cooking system and fuel used (e.g. electric cooker, kitchen range)		X	

	Location of kitchen (zone 1 or 2)	Assumed zone 2							
								No of full meals (excluding breakfast) cooked per week	
								Microwave, power rating, and frequency of use for heating pre-prepared food	
Lighting	Proportion of light bulbs that are low energy	Assumed none				Percentage of low energy light bulbs in use		Number of low energy lightbulbs in use and where used as the main source of light (options as for portable electric heaters)	
Appliances								Ownership of cold and wet appliances, purchased before/after Jan 1st 1995, energy efficiency rating (if applicable and if known)	
								Presence of other always on appliances (open-ended question)	

								Frequency of use of wet appliances, plus air-drying of clothes in warm weather	
								Washing machine/washer-dryer connected to hot water suppy (Y/N)	
								Frost-free freezers	
								TVs, type, and largest screen size	
								No. of digiboxes	
								No. computers, excluding laptops and notebooks	
								Broadband connection (none, always on, not always on)	
Other details		No. open fireplaces						No. open chimneys	
		Electricity meter type (single, dual, unknown)						X	From billing data
								Tenure	

								Energy efficiency grant obtained (Y/N) date, used for, cost covered (all or most/little or nothing) source of grant, source of grant info	
								Transport questions (collected for Strathclyde Uni)	
								Reasons and prompt for measures taken to improve energy efficiency	
Occupancy	Number of occupants	Map / BREDEM-8 formula						Number of occupants (adults and children)	
	Demand temperature for each zone	BREDEM-8 default							
	Heating periods (for each zone if different)	BREDEM-8 default							

	Levels of usage of hot water, lights and appliances, and cooking (above average, average, below average or well below average	BREDEM-8 average level calculation						See individual sections on water heating and appliances. Lighting use based on occupancy data.	
								Home working	
								Education (highest level achieved by a member of the household)	

Appendix 2: NHER Level 1 Site Survey Form for Houses and Bungalows

NHER SITE SURVEY FORM (HOUSES AND BUNGALOWS)

English Version. 3.5x (01/01)

Property address — Office number: — Reference no: — Postcode:

Build Form: Detached ☐ Semi-Detached ☐ End-Terrace ☐ Mid-Terrace ☐ Terrace with passsage ☐ Back-Back (mid) ☐ Back-Back (end) ☐

House Age: Pre 1900 ☐ 1900-29 ☐ 1930-49 ☐ 1950-65 ☐ 1966-76 ☐ 1977-81 ☐ 1982-89 ☐ 1990-95 ☐ Post '95 ☐

Extension Age: Pre 1900 ☐ 1900-29 ☐ 1930-49 ☐ 1950-65 ☐ 1966-76 ☐ 1977-81 ☐ 1982-89 ☐ 1990-95 ☐ Post '95 ☐

Areas (m^2) and details

Dimensions (please tick one) Internal ☐ External ☐

Level	House	Extension	Conservatory	Room height (m)
Roof Rooms				
Third				
Second				
First				
Ground				
Basement				

Room in the roof half wall? ☐
Number of rooms (incl. hall) **Or complete ED3** ☐
Number of open chimneys **Or complete ED4** ☐
House exposed perimeter (m) ☐
Extension exposed perimeter (m) ☐
Conservatory glazed perimeter (m) ☐
Conservatory double glazed ☐

Wall construction

Wall type: Stone ☐ Solid Brick ☐ Cavity ☐ Filled Cavity ☐ Timber Frame ☐ Other ....

Extension wall: Stone ☐ Solid Brick ☐ Cavity ☐ Filled Cavity ☐ Timber Frame ☐ Other ....

Roof type: Pitched ☐ Flat ☐ Thatched ☐ Other (specify) ....

Extension roof type: Pitched ☐ Flat ☐ Thatched ☐ Other (specify) ....

Loft insulation: None ☐ 25mm ☐ 50mm ☐ 75mm ☐ 100mm ☐ 150mm ☐ >150mm ☐ Don't know ☐

Extension loft: None ☐ 25mm ☐ 50mm ☐ 75mm ☐ 100mm ☐ 150mm ☐ >150mm ☐ Don't know ☐

Window frames and Glazing (Or complete ED2)

Wood S/G ....% Metal S/G ....% uPVC S/G ....% Other (specify) ....%
Wood D/G ....% Metal D/G ....% uPVC D/G ....% Other (specify) ....%

MAIN HEATING (Or complete ED1)

System Type: Radiator system ☐ Storage Heaters ☐ Room Heaters ☐ Underfloor ☐ Warm Air ☐ Ceiling ☐

Fuel Type: Gas (mains) ☐ LPG ☐ Oil ☐ Coal ☐ Anthracite ☐ Smokeless ☐ On-Peak ☐ Off-Peak ☐

Gas boiler: Make/Model/Number ....

BOILER TYPE Normal ☐ Combi ☐ Condensing ☐ Back boiler ☐
FLUE TYPE Open ☐ Balanced ☐ Fan
MOUNTING Wall ☐ Floor ☐

Oil boiler: Condensing ☐

Solid fuel boiler: *BOILER TYPE* Boiler/range ☐ Open + Back boiler ☐ Closed + Back boiler ☐

Room heater/ storage heater:
GAS ROOM HEATER pre 1960 ☐ Standard ☐ Condensing ☐ + Back boiler ☐
STORAGE HEATERS Old - large volume ☐ Modern - slimline ☐ Automatic ☐ Fan assisted ☐
SOLID FUEL HEATERS Open fire ☐ Closed fire ☐ + Back boiler ☐

Controls: None ☐ Room stat (s)................ Programmer ☐ TRVs...........% Cylinder stat ☐

Secondary heating: None ☐ Gas flame effect open to chimney ☐ Gas flame effect flued ☐ Gas other ☐ Solid fuel open fire ☐ Solid fuel closed fire ☐ Electric heater ☐

Extent of Heating: All/almost all rooms ☐ Downstairs ☐ Living room only ☐

Water heating: From boiler/main heating ☐ Dual immersion ☐ Single immersion ☐ (off-peak) ☐ Electric instant ☐
Gas instant single-point ☐ Gas instant multi-point ☐ Kitchen range ☐ Fuel..........................

H/W cylinder ins: None ☐ Poor jacket ☐ Good jacket ☐ Spray foam ☐ No access to cylinder ☐

H/W cylinder size: Normal (90-130 ltr) ☐ Medium (130-170) ltr) ☐ Large (>170 ltr) ☐

Customer's name & address (if different from overleaf)	Postcode:
Additional Miscellaneous Information	Drylining ☐ External cladding ☐ Solar panels ☐ Mechanical ventilation ☐ with heat recovery? ☐
Cooker Type	Gas cooker ☐ Electric cooker ☐ Gas hob & electric oven ☐ Gas kitchen range ☐ Solid fuel kitchen range ☐ Oil kitchen range ☐
Lighting	Percentage of rooms with low energy lights ....%
Measures that should NOT be recommended	☐ Wall insulation *If walls are damp, the pointing is inadequate or it is a very exposed site* ☐ Loft insulation *If there is evidence of condensation in the loft space, or inadequate space* ☐ Draught proofing *If there is condensation on the walls or windows or professional draught proofing or replacement single glazed windows* ☐ Double glazing *If listed building* ☐ Cylinder insulation *If no access to cylinder* ☐ Heating upgrade *If new heating system installed*
Additional notes	

Reference number ☐ **Property postcode** ☐

Surveyor name ☐ **Date of survey** / /

Sketch Plan
Mark the position of garage or extension. Indicate adjoining buildings. Mark dimensions in meters.

Appendix 3: Pilot Project Questionnaire Pack

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DE MONTFORT UNIVERSITY
LEICESTER • BEDFORD • MILTON KEYNES

CityForm
The Sustainable Urban Form Consortium

Institute of Energy and Sustainable Development
De Montfort University
Leicester
LE1 9BH

Dear Occupier,

We are writing to request your help with an investigation into sustainable living in urban areas, in association with universities in Oxford, Sheffield, Edinburgh and Glasgow.

Your home has been selected as it lies within one of our three study areas in Leicester, which have been identified as representative of typical urban environments.

This letter contains a questionnaire on energy use and some supplementary information to help you answer the questions, should you need it. Hopefully this will take you no more than 10-15 minutes. The questionnaire will be collected early next week.

At the end of the questionnaire is a form asking for your permission for you to give us your permission to request details of your energy consumption from your supplier(s). This is a very useful and important aspect of the work as it will enable us to compare the questionnaire replies with real energy consumption figures. Any information you are kind enough to provide will be treated confidentially and will not be passed to any other organisation.

In return for your efforts we can offer you some advice on how to improve the energy efficiency of your home and help lower your energy bills.

Another questionnaire on different aspects of our work may be issued to you later. It is essential to us that we receive answers to both questionnaires for each selected household, so we hope you will be able to help us again. However, if you do not wish to be contacted again please tick the box at the end of the questionnaire.

If you have any questions regarding any aspect of this survey please feel free to call Keith Baker on 0116 257 7966 or e-mail kbaker@dmu.ac.uk .

Thank you very much for your time and help

Yours faithfully,

Keith J. Baker,
Research student
IESD, De Montfort University

Sustainable Urban Form Consortium Energy Questionnaire

1. Property address: **Postcode:**	____________________ ____________________ ____________________ ____________________
2. Home Type	Detached ☐ Semi-Detached ☐ End-Terrace ☐ Mid-Terrace ☐ Terrace with Passage ☐ Back-Back (mid) ☐ Back-Back (end) ☐ Maisonette ☐ Flat ☐ Tenement ☐ - if so floor ____ of ____
3. When built	Pre 1900 ☐ 1900-29 ☐ 1930-49 ☐ 1950-65 ☐ 1966-76 ☐ 1977-81 ☐ 1982-89 ☐ 1990-95 ☐ Post 1995 ☐
4. Building details	**No. of floors** ____ **No. of bedrooms** ____ **Total no. of rooms** ____ **Basement?** Yes/No **Cellar?** Yes/No **Conservatory?** Yes/No - if Yes is it heated? Yes/No – is it double glazed? Yes/No - what is its orientation (front/back/side)? __________ **No. of open chimneys** (if any) ____
5. Walls and roof	**Wall type:** Stone ☐ Solid Brick ☐ Cavity ☐ Filled Cavity ☐ Timber Frame ☐ Other (specify) ____________________ **Number of shared walls:** ______ **Roof type:** Pitched ☐ Flat ☐ Other (specify) ____________ **Loft insulation** (if known, please pick closest) None ☐ 25mm ☐ 50mm ☐ 75mm ☐ 100mm ☐ 150mm ☐ >150mm ☐ Don't know ☐
6. Windows, frames and glazing	Please tick the box that describes the majority of your glazing according to its orientation (leave a section blank if there are no windows in that aspect):

	Front	Back	Sides
Wood – single glazed	☐	☐	☐
Wood – double glazed	☐	☐	☐
Metal – single glazed	☐	☐	☐
Metal – double glazed	☐	☐	☐
uPVC – single glazed	☐	☐	☐
uPVC – double glazed	☐	☐	☐
Other – single glazed	☐	☐	☐
Other – double glazed	☐	☐	☐

Please give brief details of any exceptions: ______________________________
____
____

7. Main heating	**System:** Radiator system ☐ Storage heaters ☐ Gas room heater ☐ Underfloor ☐ Other (specify) __________ **Fuel:** Electric ☐ Mains gas ☐ LPG ☐ Oil ☐ Coal ☐ Other (specify) ______ **Gas room heaters** (if applicable): Old ☐ Modern ☐ Condensing ☐ Back boiler? ☐ **Storage heaters** (if applicable): Old (large volume) ☐ Modern (slimline) ☐ Automatic? ☐ Fan assisted? ☐ **Solid fuel room heaters** (if applicable): Open fire ☐ Closed fire ☐ Back boiler? ☐ **Type of gas boiler** (if applicable): Normal ☐ Combi ☐ Condensing ☐ Back boiler ☐ **Type of oil boiler** (if applicable): Normal ☐ Condensing ☐ **Type of solid fuel boiler** (if applicable): Boiler/range ☐ Open + Back boiler ☐ Closed + Back boiler ☐ **Controls:** None ☐ Clock/timer design ☐ Digital (fully programmable) ☐ Zoned heating (heating programmable according to area of dwelling)? Yes/No – if Yes, how many zones? ____ If using radiators are all/most fitted with thermostatic radiator valves? Yes/No **Extent of main heating:** All/almost all rooms ☐ Downstairs only ☐ Living room only ☐
8. Secondary heating	Please tick any that are present and in regular use during cold weather: None ☐ Gas room heater ☐ Gas fire open to chimney ☐ Gas fire not open to chimney (flued) ☐ Other gas heater ☐ Solid fuel open fire ☐ Solid fuel closed fire ☐ Electric heaters (fixed to wall) ☐ - please state number: ______ Portable electric heaters ☐ - please state number in regular use during cold weather _____ Main use(s) of secondary heating: Living / dining room(s) ☐ Bedroom(s) ☐ Kitchen ☐ Bathroom ☐ Conservatory ☐ Other area(s) ☐
9. Water heating	Please tick more than one if necessary (this does not include showers as water heaters): From boiler/main heating system ☐ Single immersion ☐ Dual immersion ☐ Electric instant ☐ Gas instant single point ☐ Gas instant multi-point ☐ Kitchen range ☐ - if kitchen range please state fuel: ______________ Condition of hot water cylinder jacket: None ☐ Poor condition ☐ Good condition ☐ Spray foam ☐ No access ☐ Hot water cylinder size (approximate): Small (90-130 litres) ☐ Medium (130-170 litres) ☐ Large (>170 litres) ☐

10. Home extension details (if applicable)	**Extension age:** Pre 1900 ☐ 1900-29 ☐ 1930-49 ☐ 1950-65 ☐ 1966-76 ☐ 1977-81 ☐ 1982-89 ☐ 1990-95 ☐ Post 1995 ☐ **Extension wall:** Stone ☐ Solid Brick ☐ Cavity ☐ Filled Cavity ☐ Timber Frame ☐ Other (specify) _______________ **Extension roof type:** Pitched ☐ Flat ☐ Other (specify) ____________ **Extension loft insulation** (if known, please pick closest) None ☐ 25mm ☐ 50mm ☐ 75mm ☐ 100mm ☐ 150mm ☐ >150mm ☐ Don't know ☐
11. Lighting	How many energy saving bulbs are in use as main light sources in your home: 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ >5☐ Where are they in use as the main light source (tick any that apply): Living room ☐ Dining room ☐ Bedroom(s) ☐ Kitchen ☐ Bathroom ☐ Other area(s) ☐
12. Appliances	How many TVs do you own and use regularly? ______ Which of the following do you own and use regularly (tick all that apply): Washing machine ☐ Tumble dryer ☐ Washer-dryer ☐ Dishwasher ☐ Fridge with freezer compartment ☐ Fridge-freezer ☐ Fridge-freezer <u>and</u> separate freezer ☐ Separate fridge and freezer ☐ Microwave ☐ If you own a washer-dryer what to use <u>mainly</u> use it for? Washing ☐ Drying ☐ Washing and drying ☐ Please state which of the above (if any) were purchased after 1st January 1995: ____ ____ Approximately how many loads do you use each of the following for per week? Washing machine: ____ Tumble dryer ____ Dishwasher ____ Is your washing machine connected to your hot water supply? Yes / No / Not applicable Is your freezer a 'frost free' model? Yes / No / Not applicable Do you know the energy efficiency ratings of your major appliances (washing machine, fridge, cooker, etc)? Yes/No If yes, how many are A-rated? ___ B-rated? ____ C-rated? ____ Below C-rated?_____ Unknown? _____ How many personal computers do you own (excluding laptops)? ______ How many of these are in regular use? ______ Do you have dial-up internet access from home? Yes/No Do you have broadband internet access from home? Yes/No Cooker type: Gas ☐ Electric ☐ gas hob & electric oven ☐ Gas kitchen range ☐ Solid fuel kitchen range ☐ Oil kitchen range ☐ No cooker ☐

13. Miscellaneous information	Are you using electricity and/or gas supplied by an off-peak tariff? Yes/No Are you using electricity and/or gas supplied by a 'green tariff'? Yes/No If yes, please give tariff, electricity/gas, and provider: ________________ ______________________________ Has your dwelling been fitted with any additional cladding or insulation (usually applied directly to solid walls)? Yes/No If yes, internal ☐ or external ☐ Have you ever received a grant to improve the energy efficiency of your home? Yes/No If yes, what was it for? ________________ ______________________________ Is your dwelling fitted with solar panels? Yes/No Is your dwelling fitted with mechanical ventilation (exclude kitchen / bathroom fans)? Yes/No Are there any large trees or buildings near to your property that block out sunlight? Yes/No Approximately how many baths/showers does your household take per week? Baths ____ Showers ____
14. Tenure	**Is your home:** Owner-occupied, owned outright ☐ Owner-occupied, with mortgage ☐ Rented from council ☐ Rented from housing association ☐ Privately rented, fully furnished ☐ Privately rented, part or unfurnished ☐ University managed accommodation ☐
15. Your household	**How many people live in your home?** ____ Under 16's ____ 16-65 years old ____ Over 65's **What is the job of the highest wage earner in your household?** (Please state briefly) ________________ ______________________________ **How many people are in full-time employment? _____ Part-time? _____** **What is the highest level of education attained by a person in your household?** No formal education ☐ GCSE / 'O' level or equivalent ☐ NVQ / GNVQ or equivalent ☐ 'A' level or equivalent ☐ Degree ☐ Higher Degree ☐

Many thanks for completing this questionnaire, the information you have provided will be treated in the strictest confidence and your answers will be kept secure and anonymous

This work forms part of a national study and we or other researchers in the consortium may wish to contact you regarding further aspects of the project. If you do **not** wish to be contacted again, please tick here: ☐

. In addition to this questionnaire it would be of significant value to our study if we could obtain data on the annual energy consumption of your dwelling from your supplier, again this will be kept secure and anonymous and any conclusions drawn from it will not be linked specifically to you. In order to obtain this data we need to know who your supplier(s) is/are and written permission to obtain it from them. If you agree to this please fill in the following permission form.

I ______________________________ agree to give permission for the release of annual energy consumption data on my dwelling at

____

____

to researchers at the Institute of Energy and Sustainable Development, De Montfort University, Leicester.
My utility supplier(s) are (please state gas, electricity, etc)

____

____

____

Signed _________________________ Date ______________

Supplementary Information

Whilst we've tried to design this survey to be as simple as possible we know that we're not perfect. You'll probably be able to answer almost all of the questionnaire without getting up from your seat (and please don't go climbing into roof spaces or whatever on our behalf) however, if one of the questions relates to something you don't know and can easily check your efforts will be greatly appreciated. The following is intended to help you answer as quickly as possible and clarify any terms that may mean different things to different people.

1. Property address

We need your full address in order to link your data to our maps, and in case we need to do any follow up work. As is the case with all the information you provide, this will be kept on a secure system and not disclosed to any other parties.

2. Home type

We should have included all the different types of home within your area, however, please feel free tell us if we've missed yours out.

3. When built

If you do not know the age of your home please tick the box that represents your best guess. We have ways to double check any errors that could cause inaccuracies in our calculations.

4. Building details

The number of floors includes all levels of your dwelling that are used for living in – lounges, bedrooms, kitchens, bathrooms, etc – and not any that are used for storage (attics, cellars, etc).

The total number of rooms excludes any hallways or conservatories.

A basement is defined as a livable area and may be open on one or more sides (not all four though). A cellar is defined as non-livable and would be used for storage only. Most cellars are also completely enclosed, with little or no access to light from outside.

5. Walls and roof

Please fill this in as accurately as possible as it is an important part of how we will assess your energy efficiency, but please don't go climbing into awkward spaces for us – we'll do that ourselves in the highly unlikely event that it proves necessary.

6. Windows, frames and glazing

For our purposes the front of your home is the side facing the main road.

7. Main heating

Please tick the system that supplies heat to most rooms, and preferably also provides water heating. This is the trickiest part of the questionnaire, but as heating is a major factor in household energy consumption we need to know as much as we can.

Back boilers can be identified by water pipes entering the appliance (or chimney breast) and sometimes by radiators your home with no separate boiler. If the system is only used to provide heating please tick the back boiler box under the 'room heaters' section, if it is also used to provide hot water please tick it under the 'boilers' section.

Storage heaters are split into 'old' and 'modern'. Old ones are large, and usually brown in colour, whereas modern ones are thinner and usually white. **Automatic** heaters have a temperature sensor to switch them on and off automatically. **Fan assisted heaters** will have both a fan and a temperature sensor.

Normal boilers usually have 3 pipes entering the boiler. **Combi boilers** will have 5 or 6. They will also have a pressure gauge, no hot water cylinder, and you will probably be able to hear and/or see the boiler firing when the hot water is turned on. **Condensing boilers** will have a drain pipe (1¼ or ¾ inches wide) from the boiler to a suitable drain (either inside or outside your home). They will also have a fanned flue from which you may see steam rising on a cold day.

Gas room heaters. Any installed since 1970 will be modern models, old ones are very rare. Condensing models are also very rare but can be identified by a thin plastic flue to the outside of your home.

Controls. Almost all heating systems have some sort of control system. Older systems will have a clock/timer design and an 'on/off' switch for when you go away. Newer systems tend to be digital and can be programmed to switch on and off at different times on different days (often weekends and weekdays).

Zoned heating is currently rare, however, if you do have it you will have thermostats in more than one room. The number of thermostats is the same as the number of zones.

Thermostatic radiator values will have some form of markings on the 'on/off' knob, as opposed to normal valves which aren't marked.

Extent of main heating. This is the capability of your heating system to heat your entire home, not what you use it for. Storage heaters are always positioned to be able to heat an entire home, as are most radiator systems.

8. Secondary heating

This covers all heating not supplied by your main system, please tick all that apply.

Electric heaters (not including storage heaters) come in two forms, either fixed to the wall (i.e. they are intended to be left in place should you move house) or, more commonly, portable ones. The former are usually intended to be part of the overall heating system for your home and can be distinguished from storage heaters by being much smaller and usually needing to be switched on and off manually before and after use.

Main use(s). Please tick all areas where secondary heating is used regularly in cold weather.

9. Water heating.

Dual immersion heaters can usually be distinguished from single immersion heaters by having heating elements entering the cylinder at the top and near the bottom. **"Two-in-one"** versions have both elements (one long and one short) entering the cylinder at the top, these can be identified by two wires supplying the appliance. If your cylinder is old and has a "sink/bath" switch it is classified as a single immersion heater.

A gas single point water heater provides water immediately to the sink below it, multi-point heaters usually supply hot water to the kitchen sink and to the bathroom sink.

Cylinder size. As a rough guide a small cylinder will provide just enough hot water to fill a bath (these are often found in small flats and similar homes). Medium sized cylinders are the most common and are usually 100-150cm (approximately 3-5 feet) in height. Anything over 150cm (5 feet) is almost certainly a large cylinder.

10. Extension details

If your home has an extension, even an old one that is now part of the main body of your home, please fill this in as for the previous sections.

11. Lighting

Please tell us the number of energy saving lightbulbs in use in your home and where they are used as the main light source (i.e. are installed in the main ceiling fitting).

12. Appliances

This is one of our key areas of interest and will enable us to learn a great deal about the impact of appliance use on overall energy consumption.

TVs. Please state the number of TVs you own and use regularly, especially when different TVs are in use at the same time – for example one in the lounge and one in a child's bedroom. This does not include computer monitors.

Washer-dryers. If you own a washer-dryer please state what it is most commonly used for. This is because studies have shown many people who own them use them mainly for washing and then air-dry their clothes (sometimes after a short drying cycle).

Energy efficiency ratings. Since the mid-1990's all major appliances being sold in Europe have been given energy efficiency ratings on a scale of A to F.

Personal computers. Please state the number you own (excluding any laptop computers) and how many of these are in regular use (not in storage in cupboards, sheds, etc).

13. Miscellaneous information.

Green tariffs. If you are using electricity and/or gas from a 'green' energy supplier please tell us the name of the tariff, the name of the company and whether you buy electricity and/or gas from them. Please note that although gas isn't generated (and so is not really a 'green' fuel) many suppliers now offer it as part of their green tariffs.

Additional cladding or insulation. This specifically means insulating boards or coverings applied to walls after your home was built. It does not include additional layers of plasterboard applied to walls.

Energy efficiency grants. These are available from the council and cover things such as loft insulation. If you would like information about how to obtain a grant please feel free to say so here and we'll send you the appropriate contact details.

Solar panels. This includes panels used for both electricity production (photovoltaics) and those used for solar water heating. If you answer 'yes' to this we may well get in touch with you to ask you further questions (see the request form at the end of the questionnaire).

Mechanical ventilation. This specifically means a fan-driven ventilation system that supplies fresh air to at least half the rooms in your home and extracts air. It does not include bathroom, kitchen or cooker extractor fans, whether or not they have a direct opening to the outside. It also excludes de-humidifiers and similar 'portable' equipment.

Nearby trees and buildings. If there are any nearby trees and buildings that block large amounts of light from entering your property (not including your garden if you have one) please answer yes to this question. We will be able to pick up most of these from our maps and aerial photographs but there may be some that we are unaware of.

Baths and showers. We're not trying to find out how clean you are! This is actually a useful indicator of how you use energy.

14. Tenure

This gives us an indication of your level of freedom to modify your home.

University managed accommodation includes student halls managed by private companies for the purposes of housing students only.

15. Your household

This gives us a brief snapshot of your household and your daily routine in order to help us model how your energy use changes through the day. Please feel free to add any additional comments if you feel you are an unusual case.

Appendix 4: Pilot Project Costings

Postal Questionnaires. Costings based on the Pilot Project in Birstall, 380 packs.			
Item	**No.**	**Cost per item**	**Total cost**
Questionnaire (6 sides A4)	380	£0.13	£47.50
Consent form (1 side A4)	380	£0.01	£4.94
Guidance notes (5 sides A4)	380	£0.13	£47.50
Cover letter (1 side A4, colour headed notepaper)	380	£0.04	£14.06
Pre-paid business reply envelopes (A5, boxes of 500)	380	£0.01	£4.82
Labels, excluding printing (16 labels per A4 sheet, box of 100 sheets)	24	£0.05	£4.99
A4 envelopes	380	£0.02	£19.17
Outgoing postage (assuming 1 1st class stamp)	380	£0.30	£114.00
Return postage (2nd class, number according to response rate)	42	£0.21	£8.82
Reminder letters (1 side A4, colour headed notepaper)	360	£0.04	£14.40
Envelopes for reminder letters (A5, boxes of 500)	360	£0.01	£4.82
Postage for reminder letters (assuming 1 2nd class stamp)	360	£0.21	£75.60
		Total cost for 42 responses	£360.62
		Cost per response	£8.59

Appendix 5: The Energy Questionnaire

Address

Energy In Your Home

Dear Householder

Researchers at the Institute of Energy and Sustainable Development, De Montfort University are taking part in a nationwide research project called 'CityForm' and would greatly appreciate your help in investigating differences in energy consumption in UK homes.

You may have received a copy of the questionnaire 'The Place Where You Live' some time ago. If so we are sending you this follow-up questionnaire because you indicated your consent for us to obtain access to data regarding your energy consumption. If this is the case may we thank you for your efforts and ask you to complete this questionnaire. If this is your first contact with the project may we ask you to complete this questionnaire and consider allowing us to have access to your consumption data, especially if you are a Powergen/E-on customer (see the permission slip at the end of the questionnaire).

Your response will be an invaluable contribution to the goals of the project and will be used to inform policy to improve the sustainability of urban areas, of which energy efficiency is a key component. Your answers will be

stored securely in a format that links them to your address, but the published results (available
from our website – www.cityform.org) will not mention individual addresses, and names of respondents will be kept completely anonymous at all times. No details will be passed onto third parties at any point in the project. If you are unhappy answering any questions please leave them blank.

We ask that a householder (either an owner/joint owner or tenant/joint tenant aged 18 or over) completes this questionnaire. A pre-paid envelope is enclosed to return it.

If you would prefer to complete the questionnaire online it is available at http://www.iesd.dmu.ac.uk/~kbaker/intro.htm . We would appreciate it if you choose to do this as it will save us time processing your information, however we still request that you complete the mandate for accessing your energy consumption data and return it to us by post as your signature is required to release the information.

You may receive a reminder letter in the coming weeks, however no further CityForm questionnaires will be sent to your address. If you have any renewable energy systems installed on your dwelling or have taken any innovative measures to conserve energy we may wish to contact you to ask a few questions about how effective they are, but this will be at your convenience and only with your permission.

Thank you in advance for your help. If you have any questions please contact Dr. Mark Rylatt on 0116 257 7973 or e-mail cityform@dmu.ac.uk

EPSRC Engineering and Physical Sciences Research Council

The CityForm project is funded by the Engineering and Physical Sciences Research Council (EPSRC) and is a collaborative project involving researchers at De Montfort University, Sheffield University, Oxford Brookes, Strathclyde and Heriot-Watt.

NO. +P'CODE

Energy in Your Home

Please use the tick boxes (where provided) to answer the questions. The guidance notes provided with this questionnaire should help you answer any questions you may be uncertain about.

First, some basic details.

1. What type of home do you live in?

Detached ☐
Semi-detached ☐
End-Terrace ☐
Mid-Terrace ☐
If Terrace is there a passageway?
Yes ☐ No ☐
Maisonette ☐
Flat ☐
Tenement ☐
Other (specify)

____

If you live in a Flat or Tenement please state the floor you live on:

____
and the total number of **habitable** floors in the building: ____

2. Which of the following best describes your home?

Owner-occupied, owned outright ☐
Owner-occupied, with mortgage ☐
Rented from the Council ☐
Rented from a Housing Association ☐
Privately rented, fully furnished ☐
Privately rented, part- or unfurnished ☐
University managed accommodation ☐

3. Approximately when was it built?

Pre 1900 ☐ 1900-29 ☐
1930-49 ☐ 1950-65 ☐
1966-76 ☐ 1977-81 ☐
1982-89 ☐ 1990-95 ☐
Post 1995 ☐ Don't know ☐

4. How many floors does your home have? ___

5. How many rooms does your home have (exclude hallways and conservatories but include all others) ___

6. How many bedrooms does your home have? ____

7. Do you have a basement?
Yes ☐ No ☐

8. Do you have a cellar?
Yes ☐ No ☐

Now please tell us about the walls and roof of your home.

9. What are your walls made of?
Brick ☐
Stone ☐
Timber frame ☐
Other (specify) ______________

10. How are they insulated?
Solid wall ☐
Cavity wall ☐
Filled cavity wall ☐
Don't know ☐

11. What type of roof do you have (please tick one only)?
Pitched (sloping) ☐
Flat ☐

12. Do you have loft insulation and if so how thick is it? (Please pick the closest).
None ☐ 25mm / 1" ☐
50mm / 2" ☐ 75mm / 3" ☐
100mm / 4" ☐ 150mm / 6" ☐
More than 150mm / 6" ☐
Have insulation but don't know how thick it is ☐

Now two questions about your windows.

13. What is the main form of glazing in your windows?

Single glazing ☐
Double glazing ☐
Triple glazing ☐

14. What are the frames of most/all of your windows made of?

Wood ☐
Metal ☐
uPVC (plastic) ☐
Other (specify) ______________

How you heat your home and water has a big impact on how much energy you use. Please tell us about your heating system(s).

15. What is the main form of heating in your home (please tick one only)?

Radiator system ☐
Storage heaters ☐
Gas fire(s) / room heater(s) ☐
Solid fuel room heater(s) ☐
Underfloor heating ☐
Other (please specify type and fuel)

____

____

The following questions relate to your main heating system. Please answer the questions for the heating system you have ticked above. Leave blank those questions that do not apply.

Radiator systems.

15a. What fuel do you use?

Gas ☐
Oil ☐
Solid fuel ☐
Other fuel (specify)

____

15b. Are most of your radiators fitted with thermostatic radiator valves?

Yes ☐ No ☐ Don't know ☐

15c. Which of the following best describes your boiler (tick more than one if necessary)?

Normal/Conventional ☐
Combi ☐
Condensing ☐
Has a back boiler ☐
Don't know ☐

15d. If it has a back boiler is it open or closed?

Open ☐ Closed ☐ Don't know ☐

15e. If you have a solid fuel boiler is it a boiler/range system?

Yes ☐ No ☐

Storage heaters.

15f. Are your storage heaters old (large volume) or modern (slimline) models?

Old ☐ Modern ☐

15g. Do they have automatic controls to adjust the charge according to the weather?

Yes ☐ No ☐

15h. Are they fan-assisted?

Yes ☐ No ☐

Gas fire(s) / Room heater(s).

15i. Is it / are they old or modern?

Old ☐ Modern ☐

15j. Are any condensing models or fitted with back boilers?

Condensing ☐
Back boiler ☐

Solid fuel room heater(s).

15k. Is it / are they open or closed fire(s)?

Open fire ☐ Closed fire ☐

15l. Are any fitted with a back boiler?

Yes ☐ No ☐

Underfloor heating.

15m. What type of underfloor heating do you have?

Hot air ☐
Hot water ☐
Electric ☐
Other (specify) ______________

End of question 15.

16. Please tell us how much of your home is heated by your main heating system.

- Most or all rooms ☐
- Living / dining areas only ☐
- Bedrooms only ☐

17. Please tell us how you control your heating system.

- Mechanical Clock/Timer ☐
- Digital (programmable) ☐
- No control / Manually ☐

18. Do you have a thermostat (normally in the hall or lounge)?

Yes ☐ No ☐

18a. If yes, what temperature is it usually set to (in °C or °F)? ____

19. Is your heating system programmable for different areas of your home (zoned heating)?

Yes ☐ No ☐

19a. If yes, how many zones? __

20. Please indicate any other form of heating you use regularly in your home during cold weather (tick more than one if necessary).

- Radiator system ☐
- Storage heaters ☐
- Gas fire(s) / room heater(s) ☐
- Solid fuel room heater(s) ☐
- Underfloor heating ☐
- Electric heaters (fixed to wall) ☐
- Electric heaters (portable) ☐
- No other heating ☐

20a. If you use fixed or portable electric heaters please tell us how many you use regularly in cold weather.

Fixed to wall ______

Portable ______

21. For the heating system(s) you ticked in question 20 please tell us where it/they are used regularly during cold weather (tick any that apply).

- Living / Dining room(s) ☐
- Bedroom(s) ☐
- Kitchen ☐
- Bathroom(s) ☐
- Other area(s) ☐

22. Please tell us how you heat your water (tick any that apply).

- Single immersion ☐
- Dual Immersion ☐
- Electric instant ☐
- Gas instant single point ☐
- Gas instant multi-point ☐
- From boiler/main heating system ☐
- Kitchen range ☐

If kitchen range please state fuel:

____

Other (specify)

____

23. If you have a boiler, when was it last serviced? (If you do not have a boiler please move on to question 24).

- Within the last year ☐
- Over a year ago ☐
- Don't know ☐

23a. How old is it?

- Less than 10 years old ☐
- Older than 10 years ☐
- Don't know ☐

23b. What size (approximately) is your hot water cylinder?

- Small (90-130 litres) ☐
- Medium (130-170 litres) ☐
- Large (More than 170 litres) ☐
- Don't know ☐

23c. What type of cylinder jacket does it have?

- None ☐
- Factory fitted (spray foam) ☐
- Loose-fitting jacket ☐
- Don't know ☐

23d. If you know the make, model and number of your boiler please give it here:

____

____

Many homes have been extended at some point. The following questions concern the construction of your extension (if you have one). Please indicate whether or not this is the case and what type of extension it is. If the construction is different from that stated in questions 9-12 please also complete parts c-f. If your home has been extended more than once please complete this for the most recent one.

24. Do you have an extension (other than a conservatory)?
Yes ☐
No (go to question 25) ☐

24a. What type if extension is it?
Single storey ☐
Two storey ☐
Loft conversion ☐
Garage conversion ☐
Other (specify)

____

24b. When was it built?

Pre 1900 ☐	1900-29 ☐
1930-49 ☐	1950-65 ☐
1966-76 ☐	1977-81 ☐
1982-89 ☐	1990-95 ☐
Post 1995 ☐	Don't know ☐

24c. What are the walls made of?
Brick ☐
Stone ☐
Timber frame ☐
Other (specify) ______________

24d. What type of insulation do they have?
Solid wall ☐
Cavity wall ☐
Filled cavity wall ☐

24e. What type of roof does it have?
Pitched (sloping) ☐
Flat ☐

24f. Does it have loft insulation (and if so how thick is it)? (If you do know please pick the closest).

None ☐	25mm / 1" ☐
50mm / 2" ☐	75mm / 3" ☐
100mm / 4" ☐	150mm / 6" ☐

More than 150mm / 6" ☐
Have insulation but don't know how thick it is ☐

25. Do you have a conservatory?
Yes ☐
No (go to question 26) ☐

25a. What type of glazing does it have?
Single ☐
Double ☐
Triple ☐
Other (specify) ______________

25b. Do you heat it in cold weather?
Yes – as a living area ☐
Yes – just to protect plants ☐
No ☐

26. How many open chimneys does your home have? ________

27. Is your home fitted with mechanical ventilation (other than bathroom, kitchen or cooker fans)?
Yes ☐ No ☐

28. How many energy saving lightbulbs do you use in your home?
0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
More than 5 (state number) ______

28a. Where are they in use as the main source of light?
Living room(s) ☐
Dining room(s) ☐
Bedroom(s) ☐
Kitchen ☐
Bathroom(s) ☐
Other area(s) ☐

29. The following questions concern the major appliances you have in your home. Please indicate whether or not you have them and if they were purchased after 1st January 1995. Many appliances sold after this date are labelled with an energy efficiency rating (F to A++). Please also write this in (if known). If you have more than one of any of these additional

space is provided at the end of the question.

Washing machine ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Tumble dryer ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Washer dryer ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Dishwasher ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Fridge ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Fridge with freezer compartment ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Fridge with ice-maker ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Fridge-freezer ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________
Freezer ☐
Purchased after 1st Jan 1995 ☐
Energy efficiency rating ________

If you use more than one of any of these appliances in your home please use this space to write in type, whether it was purchased after 1st Jan 1995, and the energy efficiency rating (if applicable and known).

____
____
____
____
____

29a. Many of the appliances listed here are high energy users that are always turned on. If you have any other major appliances or devices that are always turned on or that are left on for long periods of time please list them here.

____
____
____
____
____

30. If you own a microwave do you know how much power it uses?
No microwave ☐
650W ☐
850W ☐
Other (specify) ________________
Don't know ☐

31. If you have a washing machine or washer-dryer, is it connected to the hot water supply?
Yes ☐ No ☐ Don't know ☐

32. If you have a freezer, is it a frost-free model?
Yes ☐ No ☐ Don't know ☐

33. If applicable, how many times a week do you use the following?
Washing machine _____
Tumble dryer _____
Dishwasher _____
Washer-dryer:
- Washing _____
- Drying _____

33a. Do you dry your washing outside in warm weather?
Yes ☐ No ☐

34. What type of cooker do you use?
Gas ☐
Electric ☐
Gas hob and electric oven ☐
Gas kitchen range ☐
Solid fuel kitchen range ☐
Oil kitchen range ☐
No cooker ☐
Other (specify) ________________

34a. Approximately how many times a week does your

household cook a full meal (excluding breakfast)?
____ times a week
34b. If you have a microwave approximately how many times a week do you use it to heat pre-prepared food?
____ times a week

35. Approximately how many baths and showers does your household take per week?
Showers ____
Baths ____

36. How many TVs are in regular use in your home? ____
36a. What is the largest screen size? ____ inches
36b. If any are flat-panel models, how many are:
LCD? ____
Plasma screens? ____

37. How many (if any) cable, satellite, Freeview or similar digi-boxes are in regular use? ____

38. How many personal computers are in regular use in your home (excluding laptops and notebooks)? ____

39. Do you have broadband connection?
Yes – always connected (e.g. through a cable TV box) ☐
Yes – not always connected (e.g. a BT line) ☐
No ☐

The following questions concern energy efficiency improvements you may have made to your home.

40. Has your home been fitted with any additional insulating cladding or boarding (usually applied directly to solid walls)?
Yes ☐ No ☐
40a. If yes, is it internal or external?
Internal ☐ External ☐

41. Have you ever received a grant to improve the energy efficiency of your home (please tick all that apply but do not include free energy efficient lightbulbs)?
Yes ☐
No (please go on to question 42) ☐
41a. If yes, what was it for?
Cavity wall insulation ☐
Roof / loft insulation ☐
Replacement fridge or fridge – freezer ☐
Draft proofing ☐
Central heating installation ☐
Free hot water cylinder jacket ☐
Other (please specify);

____

____

41b. And do you remember when the improvements were made (month and year if possible)?

____

41c. Did the grant pay for all or most of the work?
Yes, I paid nothing or little ☐
No, it only paid for part of the cost ☐
41d. Who was the grant given by?
WarmFront (formerly the Home Energy Efficiency Scheme – HEES) ☐
Energy / utility supplier ☐
Other (please specify)

____

____

41e. How did you find out about the grant (please tick all that apply)?
Leaflet with electricity / gas bill ☐
Energy advice stand or presentation at a public event ☐
Council leaflet through door ☐
Council leaflet at a public building ☐
Visit to an Energy Efficiency Advice Centre ☐
Energy Savings Trust phone line or website ☐

Energy Savings Trust TV / radio advertisement ☐
WarmZone / ComfortZone Scheme ☐
Through a charity or community organisation (excluding those above) ☐
Other (please specify):

____

____

42. Is your home fitted with any of the following?

Solar thermal panels ☐
Solar photovoltaic panels ☐
Wind turbine ☐
Micro combined heat and power (Micro-CHP) ☐

42a. If you have ticked any of the above is it / are they working?

Yes ☐ No ☐ Don't know ☐

42b. If you have ticked any of the boxes in this question may we contact you for more information?

Yes ☐ No ☐

43. If you have taken any steps to improve the energy efficiency of your home please tell us why (tick any that apply).

To lower energy bills ☐
For home improvement ☐
To help the environment ☐
Other (specify) ______________________________

____

43a. If you have, what prompted you to do so?

Advice from council (leaflet, etc) ☐
Visit to the energy efficiency advice centre ☐
Adverts on TV ☐
Information found on the internet ☐
Word of mouth ☐
Other (specify) ______________________________

____

Now a few questions relating to the vehicles you own and use.

We know that vehicle use doesn't contribute to your utility bills, however some studies have shown a relationship between vehicle use and household energy efficiency.

44a) Approximately how many journeys per week do members of your household make that are to places more than roughly 2 miles of your home using the following forms of transport?

____ by car
____ by motorbike/moped
____ by bus, train or tram
____ by bicycle or on foot

44b) Approximately how many journeys per week do members of your household make that are to places within roughly 2 miles of your home using the following forms of transport?

____ by car
____ by motorbike/moped
____ by bus, train or tram
____ by bicycle or on foot

44c) Approximately how much does your household spend on petrol / diesel per month?

£______________ on petrol
£______________ on diesel

Finally, some questions about your household. Although this concerns personal information it is important as it will help us compare energy use between different groups of people, and help us understand where best to target funding to help people become more energy efficient.

45. How many adults and children (under 16) live in your home?

Adults ____
Children ____

46. How many people living in your home are:

In full-time employment ____
In part-time employment ____
Students or individuals over the age of 16 in full-time education ___
Retired ____

47. Do any members of your household regularly work from home?

Yes ☐ No ☐

47a. If yes, do they use any of the following that contribute to your domestic energy bill?

Office equipment ☐
Kitchen / catering appliances (other than those ticked for question 29) ☐
Machinery (e.g. in a garage or workshop) ☐

48. Please tell us the job title of the highest wage earner in your household:

____
____
____
____

49. What is the highest level of education attained by a person living in your household?

No formal education ☐
GCSE / 'O' level or equivalent ☐
NVQ / GNVQ or equivalent ☐
HNC / HND or equivalent ☐
'A' level or equivalent ☐
Professional qualification (e.g. chartered accountant) ☐
Degree ☐
Higher Degree ☐

50. Did you need to consult the Guidance Notes to complete this questionnaire?

Yes ☐ No ☐

Many thanks for sparing us some of your time to complete this questionnaire. Your response will form an invaluable contribution to a national research project to help improve the sustainability of urban communities and improve the quality life for people living in our cities.

Details of the energy consumption of individual households (if discussed in our results) will not be published in a form that can be linked to you or your home (this is against the law).

In order for us fully assess the energy efficiency of your household we would greatly appreciate it if you could complete the permission slip on the following page. None of the information you provide us with will be passed onto third parties.

Request for energy consumption data

We need to compare your replies to our questionnaire with the energy you have actually consumed at this address for the most recent period of at least a year when your meter(s) were actually read. We are interested in the amount of energy you have consumed, not how much it has cost. If you can provide copies of fuel bills covering at least a year with actual meter readings (not estimates) then please attach them to this form. If not, we may be able to acquire this information from your supplier, from a meter reading agency or from the Department of Trade and Industry, but we cannot do so without your permission. If you consent to this please fill in the form below. We shall only request information about energy consumed.

If you would prefer us to phone or e-mail for this information then please give your contact details below and we will arrange to do so at your convenience. Please do not hesitate to contact us if we can be of any further assistance.

Phone no./e-mail address: ______________________________

Consent Form

I (Householder) ______________________ of (Address) ________________

____

Post Code:__________ (essential)

give my consent to the release of electricity and gas meter data for this address. I confirm that the data must only be provided to the institute of Energy and Sustainable Development, De Montfort University for use in research by their representatives and that it must not be disclosed to any other persons or organisations.
Please give details these details from your energy bills (the MPAN is a 21 digit number and the MPRN is a 6 to 13 digit number):

Electricity	Gas
Supplier Name: ________________	Supplier Name: ________________
Customer Number: ______________	Customer Number: ______________
MPAN:	MPRN: ____________________

Signed _________________________ Date ______________

Guidance Notes

Although we have tried to be as clear as possible, we are aware that some of the terms used on the questionnaire may not have exactly the same meaning for everybody. We hope that these numbered notes (referred to on the questionnaire) will save you time in completing the form. If you still have any doubt please add a brief comment alongside the question and move on to the next one.

Note 1.

If your house does not match any of the types included please describe it briefly.

Note 2.

University managed accommodation includes student halls managed by private companies for the purposes of housing students only.

Note 3.

If you are not sure of the age group to which your house belongs please give an estimate or tick the 'don't know' box..

Note 4.

Please include only **floors** (storeys) used as living areas, counting the ground floor and basement if appropriate (a **basement** is a heated living area below the entrance floor that may not be wholly underground whilst a **cellar** is an unheated completely underground space used only for storage). Floors used only for storage should not be included. Please do not include hallways or conservatories in the **total number of rooms** and include only spaces separated from each other by a full-height wall (e.g., do not include an eating area separated from a kitchen area by a breakfast bar or counter). Garages, workshops and sheds and other outbuildings should not be included. In the **total number of bedrooms** please include any rooms in which a bed is permanently set up, including guest rooms normally used as offices or studies. Please do not include any rooms with only a fold-out bed or futon.

Note 5.

The Imperial equivalents for **Loft insulation** are:

Millimetres	25	50	75	100	150
Inches	1	2	3	4	6

Note 6.

If most of the glazing on any outside wall does not match one of the categories (e.g. triple glazing) please indicate this on the bottom line of the table.

Note 7.

Please choose the system that supplies heat to most rooms.

Back boilers can be identified by water pipes entering the appliance (or chimney breast) or by the presence of radiators when there is no separate boiler. If you have one that is only for room heating please tick the box under the **room heaters** section, but if it is also used to provide hot water please tick under the **boilers** section.

Old storage heaters are usually large and brown in colour, **modern ones** are thinner and usually white. **Automatic heaters** have a temperature sensor to switch them on and off. **Fan assisted heaters** will have both a fan and a temperature sensor.

Conventional boilers usually have three pipes entering the boiler. **Combi boilers** will have five or six pipes, a pressure gauge, no hot water cylinder, and you will probably be able to hear and/or see the boiler firing when the hot water is turned on. **Condensing boilers** will have a drain pipe (1¼ or ¾ inches wide) from the boiler to a suitable drain (either inside or outside your home) and a fanned flue.

Gas room heaters are likely to have been installed since 1970, older ones are very rare. **Condensing** gas room heaters are unusual but if you have one it can be identified by a thin plastic flue on the outside wall.

Most heating systems have visible **controls**. Older systems will have a clock/timer and an 'on/off' switch. Newer systems tend to be digital and can be programmed to switch on and off at different times.

Note 8.

Thermostatic radiator valves have a number of intermediate heat settings marked on the control knob, rather than just "On/Off".

Zoned heating is unusual but can be recognized by the presence of thermostats (other than thermostatic radiator valves) in more than one room (one for each zone)

Note 9.

Please tick all forms of heating you use **in addition to** your main system.

Electric heaters may be portable or permanently fixed to the wall (they are usually much smaller than storage heaters and need to be switched on and off manually).

Please tick all areas where **secondary heating** is in regular use in cold weather.

Note 10.

Dual immersion heaters, unlike single ones, usually have heating elements entering the cylinder at the top and near the bottom. **"Two-in-one"** versions have both elements (one long and one short) entering the cylinder at the top and should have two visible electrical connections. (If your cylinder is old and has a "sink/bath" switch please tick the **single** box).

A **gas single point water heater** provides water immediately to the sink below, **multi-point heaters** usually supply hot water to the kitchen sink and to the bathroom sink.

A **small sized cylinder** bath (typical in small flats and homes) is one that provides just enough hot water to fill a bath. **Medium sized cylinders** are those typically 100-150cm (approximately 3-5 feet) in height. If your cylinder is larger than this please tick the **large** box.

Note 11.

If your home has an extension, whenever it was built, please complete this section in the same way as the previous sections.

Note 12.

Please indicate the number of energy saving lightbulbs where they provide the main light source.

Note 13.

Even if the appliance is provided as part of a rented property please tick it as 'owned'.

Please state the number of **televisions (excluding computer monitors)** you own and use regularly.
Energy efficiency ratings on a scale of A to F should be found on most modern appliances.
Please state the number of **personal computers** (PCs) used regularly in your home (excluding any laptop computers).

Note 14.
Mechanical ventilation is a fan-driven system, supplying and extracting air in at least half the rooms in your home, not separate bathroom, kitchen or cooker extractor fans (whether or not they have a direct opening to the outside) or de-humidifiers and similar 'portable' equipment.

Note 15.
The number of baths and showers is related to the amount of energy you use so please estimate this as accurately as possible.
If you are using electricity and/or gas from a 'green' energy supplier (on a **green tariff**) please tell us the name of the tariff, the name of the company and whether you buy electricity and/or gas from them.
Additional cladding or insulation specifically means insulation boards or coverings applied to walls after your home was built and does not include additional layers of plasterboard fixed to internal walls.
Energy efficiency grants are available from the Council (e.g. for loft insulation).
Solar panels include those used for electricity production (solar photovoltaics) and for solar water heating.
Energy efficiency improvements are physical changes to the fabric or contents of your home and may be quite small (e.g. buying an energy efficient washing machine) or much bigger (e.g grants for loft insulation, new windows, or even solar panels). Do not include behavioural changes such as switching off lights when leaving a room.

Appendix 6: Working paper on the development of an online version of the questionnaire

Development of an online version of the questionnaire

The issue of whether or not to use a multi-modal approach (postal and online) was discussed during the production of the version of the energy questionnaire used in the pilot project. At that stage it was felt that developing an online version was too onerous a task for a mere 373 targeted addresses, however with expanded sample sizes of around 1600 addresses per study area being envisioned for the extended work, and in light of the relatively low response rate from the pilot study, it was decided to re-visit the idea of providing an online option.

Adopting a multi-modal strategy requires addressing several key issues, some of which are common to most questionnaire-based research, and others that are peculiar to the work in question. The next few sections address these issues and explain the reasoning behind the decision to produce the online version.

How does multi-modal sampling affect the accuracy and generalisability of survey results?

This is the key question for researchers choosing a multi-modal approach to surveying and has been the subject of much discussion. De Leeuw (2005) identifies several factors that are useful for putting a specific multi-modal strategy in the context of the wider discussion, these being media-related factors, factors influencing information transmission, and interviewer effects. Media-related factors are the social conventions associated with a particular survey mode, including the likely familiarity of respondents with the mode, how it is used, and the locus of control in the question and answer process. Information transmission includes how the survey is presented (visually, orally, or both) but may also be dependent on the social conventions associated with the form of presentation, especially where questions are presented in the same form but in different media. Interviewer effects concern the availability of different forms of communication when conducting surveys, e.g. the ability of a face-to-face interviewee to gain non-verbal information from the interviewer which would not be possible in a telephone interview, however in this case these latter factors are irrelevant and will not be discussed further.

In the case of a postal/online survey there may be some reasons to suggest that differences in the accuracy of completed questionnaires may exist between written and online responses. One difference, as cited by Dillman (2005) is that online versions of questionnaires may exploit the media by providing additional information visually and/or orally. Whilst an audio accompaniment to a questionnaire may obviously enhance the level of information provided to respondents, even something as simple as the difference between providing a colour image online and a black and white image in the paper version could conceivably affect the level of information being communicated in each case. In theory this advocates a strategy of making postal and online versions as similar as possible.

Conversely, as argued by De Leeuw (2005) responses to online questionnaires may be less accurate as the media is more prone to allowing for more superficial cognitive processing as respondents read through the questions. The most obvious reason for this is that respondents opting to complete online may well be multi-tasking – i.e. reading other webpages or working at the same time – and therefore not devoting all of their attention to the task.

A variation on this reasoning is how the online version is delivered, which breaks down into two factors, both of which are relevant to the design of the energy questionnaire. The first concerns how, and if, the online questionnaire is divided up over two or more linked webpages. Division over multiple pages allows designers to minimise download times and thus, in theory at least, improve response rates by reducing the likelihood that respondents will simply get fed up of waiting for the questionnaire to download and therefore not complete it. This applies both to forms designed only for completion online and those that can be printed out and returned by post.

The problem with division is that respondents may loose the context of the questions they are answering. Respondents answering a printed questionnaire can easily flip back to previously answered questions if they feel they are loosing the context of the survey. This is not impossible with online versions but download times need to be accounted for and, as is the case with many online surveys, the software being used may dictate that respondents are required to re-complete questions after having navigated back to a previous page.

The other aspect of the division problem occurs when supplementary information is being provided to aid survey completion. As discussed in section 3.4. many online surveys provide supplementary information alongside the relevant questions, often in the form of images. Opting for this approach returns us to the issues of download time and differences in appearance between online and postal versions. Deciding against this approach requires presenting the supplementary information on a separate page. Excluding the extreme minority of people who use two monitors attached to the same computer, this approach assumes that respondents will either flick between the page containing the questionnaire and the page containing the supplementary information or print out the supplementary information. The former option may enhance the tendency for superficial cognitive processing mentioned by De Leeuw, whereas the latter should reduce it as respondents are able to refer directly from one to another without switching from one window to another. However, without specifically including a question asking which was used by online respondents it is impossible to deduce a causal relationship between the choice of option and the accuracy of the information acquired.

In terms of how generalisable the results of a postal/online multi-mode survey should be, the work of Yun & Trumbo (2000) failed to find significant differences or bias in substantive analyses of data collected from postal, e-mail and online versions of a survey. It should be noted that the survey in question was conducted amongst the National Association of Science Writers and was intended to evaluate their use of e-mail and web-based services. However, in the case of the energy questionnaire its should also be noted that investigating the impact of socio-demographic differences amongst respondents is one of the issues being investigated, and that the questionnaire contains a question asking whether respondents have either dial-up or broadband internet access from home. Therefore the issue of bias from socio-demographic differences is irrelevant in terms of the respondents' choice of media, and it will also be possible to analyse individual responses in terms of whether or not respondents had the option of completing the questionnaire online at home.

How does multi-modal sampling affect response rates?

The goal of improving on the relatively low response rate to the pilot questionnaire was the main consideration behind the decision to re-visit the idea of hosting a version of the energy questionnaire online. Therefore it is important to address the question of whether or not published work supports this assertion.

Leece et al. (2004) have shown that in a comparison of response rates to postal and online questionnaires the postal option returns a higher number of responses. Sheehan (2002) notes that, in the US at least, responses to online surveys rose sharply with the increase in the number of people having internet access from home, but that that trend is now in steady decline as the number of online surveys is still increasing. As the UK has followed a similar trend with regard to internet access it seems fair to infer that a similar trend will occur here.

What none of these studies really address is whether or not a potential respondent who receives a questionnaire through the post will opt to complete it online, and why. The results of the energy study may unintentionally throw some light on this question, and the issue of how many additional respondents decide to complete the questionnaire because of the perceived ease of the online option. However, in this case it should be noted that the questionnaire also asks for the completion of a mandate form that must be signed and returned by post, and therefore it will be interesting to see how many, if any, respondents complete the form online and also return a mandate.

Other considerations for producing an online option

One of the key reasons the studies here assert for choosing to produce or replicate surveys online is the issue of cost. Whilst online hosting may be expensive for some, researchers usually have the benefits of free hosting and technical support at their universities. There is, of course, always the option to pay for a professional to produce and host a survey, e.g. at www.surveymonkey.com , but a basic design can be produced fairly easily using FrontPage and a little help. Therefore this can be a very cost effective approach. Another reason for not paying a professional is the greater control over how the returned data is coded and stored.

Furthermore, where a large number of respondents are being targeted and/or a large number of questions are being asked (which is true in both respects for the energy study) an online-only strategy saves vast amounts of time on envelope stuffing and data entry even when compared to a few days to set up and a week or so to de-bug.

A final consideration for the energy study was the intention to seek respondents outside of the study areas to gain data that could be used to validate the conclusions drawn from the information provided by those being targeted directly. The intention being to use university e-mail lists as a main source of additional respondents within the five cities, but not to the point of excluding anyone willing to spare the time.

In summary, the potential added value of providing an online option for the energy study far out-weighed the additional work required, and given that the few concerns raised in studies of multi-modal sampling are largely irrelevant due to the nature of the questionnaire it was decided to pursue this strategy.

The final version of the online questionnaire

In light of the preceding discussion the primary aims in the development of the online version of the energy questionnaire was to make it resemble the postal version as closely as possible and be as quick as possible to download. Both aims were largely met.

The revised format and content of the questionnaire was much more appropriate for adaption than that of the version used for the pilot study, in part because the idea of an online version was being discussed during the revision period. The main difference, using a single-column layout, is more sensible for web users used to scrolling down but not back up. Keeping the format as basic as possible was also a solution to minimising download times, however the length of the questionnaire necessitated its division over seven pages to reduce the maximum download time to 21 seconds over a 28.8k dial-up connection, which was deemed as acceptable.

Using a mix of radio buttons and tick-boxes was a means of ensuring that respondents asked to 'tick one only' could not give multiple answers, something that is not possible in self-administered postal surveys. Text boxes could also be sized suitably to give an indication of the amount of information being asked for in each case, and the fields for house number and postcode were kept to the end and made mandatory in the hope that anyone who had bothered to complete the questionnaire but did not want to give this information would be more inclined to do so than write off the estimated completion time of 10-15 minutes as time wasted.

The coding system used was deliberately the same as that for the postal version, and an SPSS input file was produced that enabled data from the online version (in .csv format) could be copied straight in.

The supplementary notes and mandate form were provided as .pdf files linked from the front page and visitors were given contact details to request an SAE to return the mandate in.

The basic setting up of the webpages from scratch took a mere 2-3 days plus about 2 weeks of occasional de-bugging. In terms of real time spent this compares well to a week spent stuffing envelopes for just one study area (which does not include printing time).

Appendix 7: Table of r^2 values

Data category	Study area	Sub category	Number of records	Variables	R2	Comments
Energy consumption	Leicester		52	Elec vs TFA	0.1479	
			40	Gas vs TFA	0.2312	
	Sheffield, Detached		46	Elec vs TFA	0.0518	
			42	Gas vs TFA	0.4023	
	Sheffield, Semis		52	Elec vs TFA	0.0023	
			47	Gas vs TFA	0.0787	
	Sheffield, Flats		12	Elec vs TFA	0.0096	
			9	Gas vs TFA	0.2578	
Built form	Leicester	Mid-terraces	19	Elec vs TFA	0.2047	
			14	Gas vs TFA	0.4429	
		Mid-terrace with passageway	25	Elec vs TFA	0.0728	
			20	Gas vs TFA	0.4113	
		End terrace	4	Elec vs TFA	Not plotted	
			4	Gas vs TFA	Not plotted	
		End terrace with passageway	4	Elec vs TFA	Not plotted	
			3	Gas vs TFA	Not plotted	
Tenure	Leicester	Owner-occupied, Owned outright	24	Elec vs TFA	0.1171	R2 rises to 0.29 with 1 potential outlier removed
			19	Gas vs TFA	0.0961	R2 is 0.49 with 1 potential outlier removed (not the same record as for E vs TFA)
		Owner occupied, with mortgage	18	Elec vs TFA	0.0919	
			13	Gas vs TFA	0.3789	

		All rented properties	10	Elec vs TFA	0.4552	R2 is 0.56 with 2 potential outliers removed
			8	Gas vs TFA	0.4302	
	Sheffield, Detached	Owner-occupied, Owned outright	37	Elec vs TFA	0.1262	
			33	Gas vs TFA	0.4454	
		Owner occupied, with mortgage	9	Elec vs TFA	0.0401	
			9	Gas vs TFA	0.2418	
	Sheffield, Semis	Owner-occupied, Owned outright	29	Elec vs TFA	0.0005	
			25	Gas vs TFA	0.0682	
		Owner occupied, with mortgage	23	Elec vs TFA	0.0035	
			22	Gas vs TFA	0.1087	
Dwelling age	Leicester	Pre-1900	33	Elec vs TFA	0.1774	
			28	Gas vs TFA	0.2051	R2 is 0.49 with 1 potential outlier removed
		1900-29	15	Elec vs TFA	0.0471	
			9	Gas vs TFA	0.2081	
	Sheffield, Detached	Pre-1950	9	Elec vs TFA	0.0792	
			8	Gas vs TFA	0.9238	Very good fit, R2 is 0.8615 when forced though intercept
		1950-65	14	Elec vs TFA	0.0234	
			13	Gas vs TFA	0.035	
		1966-76	20	Elec vs TFA	0.1152	
			19	Gas vs TFA	0.0061	
	Sheffield, Semis	1900-29	9	Elec vs TFA	0.02	
			7	Gas vs TFA	0.129	
		1930-49	8	Elec vs	0.0004	

				TFA		
			7	Gas vs TFA	0.5413	
		1950-65	29	Elec vs TFA	1.00E-06	
			27	Gas vs TFA	0.0022	
		1966-76	6	Elec vs TFA	0.3283	R2 unrepresentatively high, high scatter
			5	Gas vs TFA	0.5891	R2 unrepresentatively high, high scatter
Rooms	Leicester		53	TFA vs No. Rooms	0.6123	Very interesting plot, obvious and consistent margin of error
			52	Elec vs No. of Rooms	0.1224	R2 becomes 0.3465 with 4 potential outliers removed
			40	Gas vas No. of Rooms	0.2312	R2 becomes 0.4324 with 1 potential outlier removed, and scatter becomes much more balanced
	Sheffield, Detached		48	TFA vs No. Rooms	0.4255	Very interesting plot, obvious and consistent margin of error
			46	Elec vs No. of Rooms	0.0762	Some potential outliers, but removing them makes little difference
			42	Gas vas No. of Rooms	0.4023	
	Sheffield, Semis		53	TFA vs No. Rooms	0.2092	
			52	Elec vs No. of Rooms	0.0796	
			46	Gas vas No. of Rooms	0.1451	
Bedrooms	Leicester		53	TFA vs No. Bedrooms	0.6831	Very interesting plot, obvious and consistent margin of error

			52	Elec vs No. Bedrooms	0.1498	
			39	Gas vs No. Bedrooms	0.2438	
			51	TFA vs ppb	0.0398	
			50	Elec vs ppb	0.0422	
			38	Gas vs ppb	0.1624	
	Sheffield, Detached		47	TFA vs No. Bedrooms	0.325	
			45	Elec vs No. Bedrooms	0.1569	
			41	Gas vs No. Bedrooms	0.1884	
			47	TFA vs ppb	0.0956	
			45	Elec vs ppb	0.042	
			41	Gas vs ppb	0.0016	
	Sheffield, Semis		52	TFA vs No. Bedrooms	0.1807	
			51	Elec vs No. Bedrooms	0.34	
			45	Gas vs No. Bedrooms	0.1512	
			52	TFA vs ppb	0.0002	
			51	Elec vs ppb	0.0174	
			45	Gas vs ppb	0.0005	
Wall insulation	Leicester	Solid wall	34	Elec vs TFA	0.1499	
			23	Gas vs TFA	0.1652	R2 is 0.54 with potential outlier removed
		Cavity and Filled cavity	8	Elec vs TFA	0.5538	
			9	Gas vs TFA	0.5627	
	Sheffield, Detached	Cavity	19	Elec vs TFA	0.1417	
			18	Gas vs TFA	0.7327	
		Filled cavity	24	Elec vs TFA	0.0061	
			21	Gas vs TFA	0.3074	
	Sheffield, Semis	Cavity	24	Elec vs TFA	0.0035	
			22	Gas vs TFA	0.1083	
		Filled cavity	21	Elec vs	0.0084	

				TFA		
			20	Gas vs TFA	0.0057	
Loft insulation	Leicester		29	Elec vs Loft insulation	0.0832	
			21	Gas vs Loft insulation	0.0047	
	Sheffield, Detached		39	Elec vs Loft insulation	0.0009	
			36	Gas vs Loft insulation	9.00E-06	
	Sheffield, Semis		40	Elec vs Loft insulation	0.011	
			37	Gas vs Loft insulation	0.0019	
Glazing	Leicester	Single glazed	24	Elec vs TFA	0.392	
			19	Gas vs TFA	0.3101	
		Double glazed	28	Elec vs TFA	0.2011	
			20	Gas vs TFA	0.6806	
	Sheffield, Detached	Double glazed	44	Elec vs TFA	0.0259	
			40	Gas vs TFA	0.2449	
	Sheffield, Semis	Double glazed	49	Elec vs TFA	0.0032	
			44	Gas vs TFA	0.0817	
TRVs	Leicester	No TRVs	24	Elec vs TFA	0.1705	R2 is 0.1727 with 1 potential outlier removed
			16	Gas vs TFA	4.00E-05	R2 is 0.0554 with 1 potential outlier removed
		TRVs present	26	Elec vs TFA	0.1155	
			23	Gas vs TFA	0.514	
	Sheffield, Detached	No TRVs	17	Elec vs TFA	0.2228	
			12	Gas vs TFA	0.48	
		TRVs present	20	Elec vs TFA	0.0887	
			20	Gas vs TFA	0.5486	

	Sheffield, Semis	No TRVs	21	Elec vs TFA	0.362	
			19	Gas vs TFA	0.1543	
		TRVs present	31	Elec vs TFA	4.00E-06	
			28	Gas vs TFA	0.392	
Boiler type	Leicester	Normal boilers	13	Elec vs TFA	0.4082	
			8	Gas vs TFA	0.7315	
		Combi and condensing boilers	29	Elec vs TFA	0.1457	
			25	Gas vs TFA	0.382	
	Sheffield, Detached	Normal boilers	26	Elec vs TFA	0.2003	
			21	Gas vs TFA	0.5282	
		Combi and condensing boilers	21	Elec vs TFA	0.0008	
			21	Gas vs TFA	0.2616	
	Sheffield, Semis	Normal boilers	26	Elec vs TFA	0.0145	
			25	Gas vs TFA	0.0625	
		Combi and condensing boilers	26	Elec vs TFA	0.0003	
			22	Gas vs TFA	0.0915	
Gas ducted warm air systems	Sheffield, Detached		9	Elec vs TFA	0.0246	
			10	Gas vs TFA	0.107	
Thermostats	Leicester	No thermostat	38	Elec vs TFA	0.1576	
			29	Gas vs TFA	0.1628	R2 is 0.3752 with 1 potential outlier removed
		Thermostat	14	Elec vs TFA	0.2238	
			10	Gas vs TFA	0.7012	Good fit to linear

	Sheffield, Detached	No thermostat	7	Elec vs TFA	0.5694	R2 unrepresentatively high, high scatter
			7	Gas vs TFA	0.6785	R2 unrepresentatively high, high scatter
		Thermostat	39	Elec vs TFA	0.0104	High scatter
			35	Gas vs TFA	0.3582	
	Sheffield, Semis	No thermostat	13	Elec vs TFA	0.0104	High scatter
			11	Gas vs TFA	0.0902	High scatter
		Thermostat	39	Elec vs TFA	0.001	High scatter
			36	Gas vs TFA	0.0786	High scatter
Thermostat settings	Leicester		15	TFA vs Thermostat setting	0.1031	
			14	Elec vs Thermostat setting	0.0141	
			13	Gas vs Thermostat setting	0.1231	
	Sheffield, Detached		38	TFA vs Thermostat setting	0.0066	
			37	Elec vs Thermostat setting	0.1041	
			33	Gas vs Thermostat setting	0.0154	
	Sheffield, Semis		34	TFA vs Thermostat setting	0.0009	
			34	Elec vs Thermostat setting	0.0774	
			30	Gas vs Thermostat setting	0.1092	
Heating controls	Leicester	Mechanical timers	22	Elec vs TFA	0.0241	R2 is 0.1143 with 1 outlier removed
			20	Gas vs TFA	0.2137	R2 is 0.3299 with 1 outlier removed

		Digital controls	20	Elec vs TFA	0.2576	
			14	Gas vs TFA	0.525	
	Sheffield, Detached	Mechanical timers	21	Elec vs TFA	0.0403	
			19	Gas vs TFA	0.5721	
		Digital controls	23	Elec vs TFA	0.075	
			21	Gas vs TFA	0.4372	
	Sheffield, Semis	Mechanical timers	27	Elec vs TFA	0.0003	
			25	Gas vs TFA	0.0696	
		Digital controls	25	Elec vs TFA	0.0256	
			22	Gas vs TFA	0.2201	
Energy Efficient Lightbulbs	Leicester		42	TFA vs No. EEBs	0.0022	
			41	Elec vs No. EEBs	0.0012	
			34	Gas vs No. EEBs	0.0273	
	Sheffield, Detached		43	TFA vs No. EEBs	0.0015	
			41	Elec vs No. EEBs	0.0915	
			37	Gas vs No. EEBs	0.002	
	Sheffield, Semis		46	TFA vs No. EEBs	0.0084	
			45	Elec vs No. EEBs	0.001	
			40	Gas vs No. EEBs	0.0004	
Occupancy	Leicester	All households	51	TFA vs Total Occupants	0.1463	
			50	Elec vs Total Occupants	0.1777	
			40	Gas vs Total Occupants	0.4895	
		Single person households	17	Elec vs TFA	0.0237	
			14	Gas vs TFA	0.2891	

		Two person households	19	Elec vs TFA	0.2863	
			15	Gas vs TFA	0.2507	
		Family households	7	Elec vs TFA	0.035	
			6	Gas vs TFA	0.2987	
	Sheffield, Detached	All households	47	TFA vs Total Occupants	0.0241	
			46	Elec vs Total Occupants	0.2119	
			42	Gas vs Total Occupants	0.1007	
		Single person households	7	Elec vs TFA	0.4411	
			4	Gas vs TFA	0.3865	
		Two person households	23	Elec vs TFA	0.0363	
			23	Gas vs TFA	0.0131	
		Three person households	7	Elec vs TFA	0.4421	
			7	Gas vs TFA	0.8471	
		Family households	7	Elec vs TFA	0.01	High scatter, few records, effectively meaningless
			7	Gas vs TFA	0.4721	
	Sheffield, Semis	All households	53	TFA vs Total Occupants	0.0671	
			52	Elec vs Total Occupants	0.1706	
			48	Gas vs Total Occupants	0.0221	
		Single person households	13	Elec vs TFA	0.0317	
			13	Gas vs TFA	0.0233	
		Two person households	25	Elec vs TFA	0.0209	
			23	Gas vs TFA	0.0814	
		Family households	8	Elec vs TFA	0.2863	

			6	Gas vs TFA	0.1007	High scatter, few records, effectively meaningless
Employment	Leicester	2 person, FT employed	12	Elec vs TFA	0.4424	
			10	Gas vs TFA	0.7837	Few records but very close to linear
		1-2 person, Retired	11	Elec vs TFA	0.0302	
			8	Gas vs TFA	0.5294	Unrepresentatively high, points in two small groups at either end
	Sheffield, Detached	All retired	25	Elec vs TFA	0.01	
			20	Gas vs TFA	0.1161	
		1 person retired	7	Elec vs TFA	0.4411	
			4	Gas vs TFA	0.3865	
		2 person retired	18	Elec vs TFA	0.0159	
			16	Gas vs TFA	0.0611	
	Sheffield, Semis	1 person FT and 1 person PT employed	8	Elec vs TFA	0.3738	
			7	Gas vs TFA	0.0533	High scatter, few records, effectively meaningless
		2 person FT employed	9	Elec vs TFA	0.0219	
			8	Gas vs TFA	3.00E-05	
		1 person retired	11	Elec vs TFA	0.0239	
			11	Gas vs TFA	0.0455	
		2 person retired	10	Elec vs TFA	0.0017	
			8	Gas vs TFA	0.0622	
Homeworkers	Leicester	No homeworkers	33	Elec vs TFA	0.1352	
			27	Gas vs TFA	0.2098	R2 is 0.5489 with 1 outlier removed
		Homeworkers	19	Elec vs TFA	0.0768	

			14	Gas vs TFA	0.0786	Very high scatter
	Sheffield, Detached	No homeworkers	35	Elec vs TFA	5.00E-06	Very high scatter
			30	Gas vs TFA	0.0184	
		Homeworkers	11	Elec vs TFA	0.3127	
			12	Gas vs TFA	0.7939	Good fit to linear, R2 is perhaps a bit high
	Sheffield, Semis	No homeworkers	43	Elec vs TFA	0.0459	
			39	Gas vs TFA	0.0482	
		Homeworkers	9	Elec vs TFA	0.2872	High scatter
			8	Gas vs TFA	0.1832	High scatter, few records, effectively meaningless